

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.

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# Cosmology in the lab

## QUEST researchers of PTB generate symmetry breaking in ion Coulomb crystals

### Especially interesting for

- developers of optical ion clocks
- fundamental research

At the QUEST Institute at PTB, a novel ion trap has been developed in which ion chains are to be used as an optical frequency standard with improved stability. Due to the very good control over the dynamics of the particles trapped therein, PTB scientists have succeeded, for the first time, in inducing spontaneous symmetry breaking in crystalline structures and in demonstrating the occurrence of crystal defects with laser-cooled ions. This allows the dynamics of phase transitions and symmetry breaking in nature to be studied in the way in which they are encountered in the most various solid-state systems and in which they have led to the creation of matter in the young universe, shortly after the Big Bang.

Within the scope of an international cooperation project with colleagues from the Los Alamos National Lab (USA), from the University of Ulm (Germany) and from the Hebrew University in Jerusalem (Israel), PTB researchers have now, for the first time, succeeded in demonstrating topological defects in an atomic-optical experiment in the laboratory. Thereby, an accurately laser-structured ion trap allows long chains of positively charged ions to be trapped and provides optimum optical access to observe single ions. The ions are loaded into this trap under ultra-high vacuum and cooled down to temperatures of a few mK. Hereby, the trapped, charged particles repel each other inside the trap due to the Coulomb interaction and, at such ultra-low temperatures, take on a crystalline structure (Figs. a–b).

If the trap properties are modified faster than information can spread due to the sound-propagation velocity, then

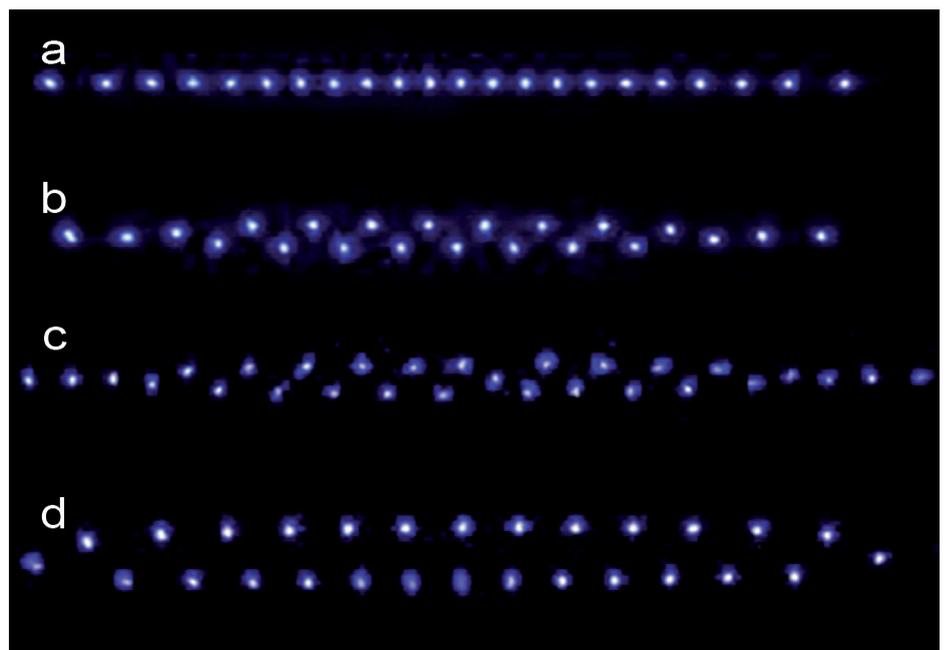


Image of Coulomb crystals consisting of ytterbium ions, taken with a camera. The ionized atoms fluoresce in the laser light; the distance between the ions is approx.  $10\ \mu\text{m}$  to  $20\ \mu\text{m}$ . The rows (a) and (b) exhibit symmetrical arrangements (linear, zigzag). In the case of (c) and (d), the symmetry is broken due to topological defects.

individual areas inside the crystal are not able to “communicate” with each other, so that topological defects may occur (Figs. c-d). Thereby, the spontaneous re-orientation of the Coulomb crystal follows the same rules as those describing the early universe after the Big Bang. The probability that defects may occur has been measured as a function of the quench rate and compared with predictions of the Kibble-Zurek mechanism in different regimes.

This theory was based on Kibble's thoughts about topological defects in the early universe: fractions of seconds after the Big Bang, a symmetry breaking took place, and the young universe had to “de-

code” which new state to adopt. Everywhere where individual areas of the universe could not communicate with each other, topological defects such as, e.g., cosmological strings and domain walls may have been created. But the Kibble-Zurek mechanism also allows statistical statements on the occurrence of defects in phase transitions in general. Due to its universal character, this theory is applicable to many fields of physics such as, e.g., the study of the transition from metals to superconductors, or the transition from ferromagnetic to paramagnetic systems. The new system now demonstrated will soon allow further experiments on phase transitions in classical systems and in the quantum world. ■

#### Contact

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#### Scientific publication

K. Pyka, J. Keller, H. L. Partner, R. Nigmatullin, T. Burgermeister, D.-M. Meier, K. Kuhlmann, A. Retzker, M.B. Plenio, W. H. Zurek, A. del Campo, T.E. Mehlstäubler: Topological defect formation and spontaneous symmetry breaking in ion Coulomb crystals. *Nat. Commun.* 4, 2291 (2013)

## Mobile xenon polarizer

New apparatus generates nuclear-spin-polarized  $^{129}\text{Xe}$  on site

#### Especially interesting for

- basic research
- biomolecular research
- biomedical imaging

A mobile apparatus to generate highly nuclear-spin-polarized  $^{129}\text{Xe}$ , a naturally abundant xenon noble gas isotope, was set up by PTB and has been used at different laboratories in Berlin for the past year to investigate issues with regard to biomedicine and to basic research in physics.

Highly nuclear-spin-polarized  $^{129}\text{Xe}$  gas is being used increasingly in different application areas. This so-called “hyperpolarized”  $^{129}\text{Xe}$ , which had originally been developed for basic research in physics and has already been successfully implemented for lung MRI, is now also used in other fields of biomedical research. But also issues having to do with understanding the structure of matter which arise in the search for theories beyond the standard model are to be investigated with hyperpolarized rare gases.

Since even under high-purity conditions, the artificially generated hyperpolarization has a lifetime of a few minutes only, the transport of hyperpolarized



The  $^{129}\text{Xe}$  polarizer (W × D × H: 130 × 64 × 152 cm<sup>3</sup>) only requires electrical power and pressurized air supply. Thanks to the modular design with the power supply units (bottom left), the evacuation unit (bottom right), the gas flow adjustment unit (centre right) and the actual polarization unit (top), the production of the polarized  $^{129}\text{Xe}$  gas can be adapted to the respective needs on site.

$^{129}\text{Xe}$  in the gaseous phase is possible only over short distances and in special glass spheres. If, in addition, highly polarized  $^{129}\text{Xe}$  has to be supplied continuously, the nuclear-spin polarization in the xe-

non gas must be generated on site in a volume flow that is adapted to the respective experiment. The process used to generate it is, however, highly complex. The mobile  $^{129}\text{Xe}$  polarizer set up at PTB fulfils all the necessary requirements for this purpose. The device can, in principle, be operated in any laboratory, since it needs no infrastructure other than electrical power and pressurized air supply. It can be shipped and commissioned again within one day. Despite its compact design, the operating mode has been kept variable: depending on the needs, hyperpolarized  $^{129}\text{Xe}$  gas can be supplied cyclically or continuously.

After having been successfully tested at PTB's Berlin laboratory last year, the polarizer was brought to Berlin-Buch, to the Leibniz-Institut für

molekulare Pharmakologie in order to be operated in connection with a magnetic-resonance micro-imager. These activities, which are carried out within the scope of BMBF and EMRP projects, aim to devel-

op methods for molecular imaging with hyperpolarized  $^{129}\text{Xe}$  at the cellular level and in small animals.

Furthermore, the polarizer's mobility and flexibility are also exploited at PTB. Here, an experiment is being prepared to search for the electrical dipole moment of xenon's nuclear spin (Xe-EDM Project in collaboration with the Technical University of Munich) for which investigations

on the nuclear spin precession in ultralow magnetic fields (nT) are being carried out at PTB's Berlin laboratories. For this purpose, the polarizer was transito-

rily operated in the direct vicinity of the magnetically shielded room (BSMR-2) to ensure optimum test conditions for this new research project. ■

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#### Scientific publication

S. E. Korchak, W. Kilian, L. Mitschang:  
*Configuration and performance of a mobile  $^{129}\text{Xe}$  polarizer.* Appl. Magn. Reson. 44, 65–80 (2013)

# How fast do vacuum gauges measure?

## Dynamic pressure standard set up

### Especially interesting for

- vacuum technology
- process technology

With a new dynamic pressure standard of PTB, pressure can be reduced from 100 kPa down to 100 Pa within 20 ms in several steps or within 1 s in a defined way, so that the time response of vacuum gauges can be investigated.

In many areas of industry, vacuum gauges must detect rapid pressure changes with a high time resolution. This is the case, for example, for the coating of PET bottles in high vacuum, the plating of CDs or DVDs, leakage tests using vacuum technology or various processes in the lighting industry, all of which require cycle times of only 1.5 s to 3 s. Whereas the manufacturers of vacuum gauges can demonstrate rather well to their customers that the electronic unit in their measuring instruments is fast enough for the controlling of such processes, the response time of the realized measuring principle to rapid pressure changes cannot be tested for the measuring heads that are exposed to vacuum.

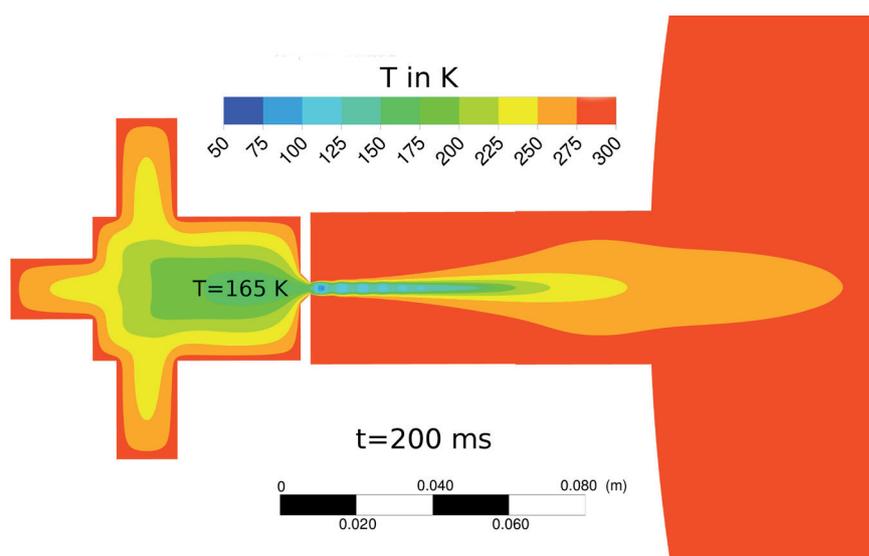
Within the scope of the European Research Project EMRP IND12, PTB has, thus, set up a dynamic vacuum standard. Hereby, the pressure is reduced by 3 decades by letting the gas expand out of a very small volume of approximately 0.1 L into a very large evacuated volume of approximately 180 L. The vacuum

gauges to be tested are flange-mounted onto the small volume. A large gate valve, which was specially developed for this purpose and can release a cross section of 12.5 cm<sup>2</sup> within 4.6 ms, lets the gas move from one volume into the other, so that the pressure inside the small volume can be reduced from 100 kPa down to 100 Pa within 20 ms. Slower expansions can also be realized by means of orifices or nozzles.

In order to determine the time response during the measurement, the experimental values are compared with calculations of the time-dependent evolution of the pressure inside the small volume during

the expansion. These simulations are very demanding since all of the three types of fluxes occur at any given time – viscous, molecular and transition fluxes – and their spatial transitions change over time. In addition, the changing geometry of the fast opening valve and the strong influences of the rapid pressure changes on the temperature have to be taken into account. In front of an orifice, a temperature drop down to approximately 165 K was calculated and measured. The simulations were carried out using the ANSYS CFX software and a program developed in-house based on OpenFOAM®.

A first series of vacuum gauges has al-



Simulation of the temperature distribution inside the small volume (left) and in the pipe leading to the large volume (right) of the pressure standard after 200 ms when the gas flows through a small orifice (centre). Directly in front of the orifice, the temperature of the gas drops down to 165 K. After 200 ms, the pressure has decreased from 100 kPa down to 8 kPa.

ready been tested at the new standard. In the case of fast capacitive membrane vacuum gauges, which had been specially developed for this project by the INFICON company, an upper limit of 1.3 ms was determined for the  $1/e$  response time in the event of a pressure change. ■

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#### Scientific publication

K. Jousten, S. Pantazis, J. Buthig, R. Model, M. Wüest, J. Iwicki: A standard to test the dynamics of vacuum gauges in the millisecond range. *Vacuum* 100, 14–17 (2013)

# Energy retrieval: waste heat converted into electricity

## Thermoelectric reference materials characterized

### Especially interesting for

- thermoelectrics
- the energy industry

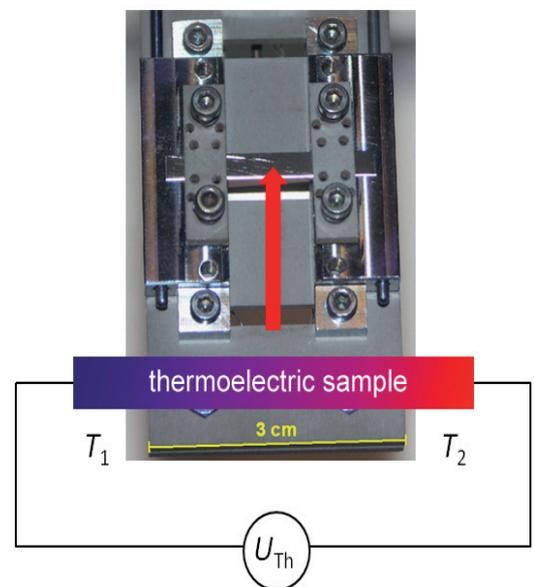
Thermoelectric materials convert thermal energy directly into electric energy – and vice versa. Thermoelectric reference materials have been metrologically characterized for the first time at PTB with regard to their Seebeck coefficients in the temperature range relevant to industry, i.e. between 300 K and 900 K. This allows the validation of the complex systems and procedures which are used to measure thermoelectric properties with regard to the achievable uncertainties and an improvement of the comparability of the results of measurements which have been carried out on diverse materials.

The natural resources for our energy supply are becoming scarce and the costs to exploit them are increasing. The energy industry must thus work ever more efficiently. Energy retrieval thereby plays an important role, because large amounts of energy are lost in the form of waste heat when technical devices and facilities are operated, whereas this thermal waste energy could be used secondarily.

For this reason, thermoelectric materials are probably going to gain in importance in the future. With these materials, the effectiveness of the energy conversion depends on their transport properties, i.e. on the Seebeck coefficient  $S$  (a temperature-dependent material parameter) as well as on the electric conductivity  $\sigma$  and on the thermal conductivity  $\kappa$ , which

are summarized in the thermoelectric figure of merit  $S^2\sigma T/\kappa$ . The exact determination of the figure of merit is the pre-condition required to assess and compare newly developed thermoelectric materials. To this end, measurements of the transport properties that are traceable to the SI units are indispensable. With the aid of the measuring system which is installed at PTB, the Seebeck coefficients and the electric conductivities of thermoelectric bulk materials and of thin layers can be measured with low measurement uncertainties.

The Seebeck coefficient describes the voltage drop caused by a temperature gradient over a sample and decisively determines the figure of merit of thermoelectric materials. Within the scope of the EMRP project “Metrology for Energy Harvesting”, reference materials have been metrologically investigated and characterized for the first time – at PTB and worldwide – with regard to their Seebeck coefficients in the higher temperature range between 300 K and 900 K. This temperature range is important for applications, e.g., in the automotive area. The measurement uncertainties attained for the Seebeck coefficients of the two reference materials ISOTAN® and bismuth-doped lead telluride lie between 2.5 % and 8 %, depending on the material and on the temperature. Both materials can be obtained from PTB. ■



Sample holder to generate an exactly defined temperature difference ( $T_2 - T_1$ ) over the sample, and measurement of the resulting thermoelectric voltage  $U_{Th} = S \cdot (T_2 - T_1)$  of the sample ( $S$ : Seebeck coefficient)

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#### Scientific publication

E. Lenz, F. Edler, P. Ziolkowski: Traceable thermoelectric measurements of Seebeck coefficients in the temperature range from 300 K to 900 K. *Int. J. Thermophys.* 34, 1975–1981 (2013)

# New correction procedure for light source measurement

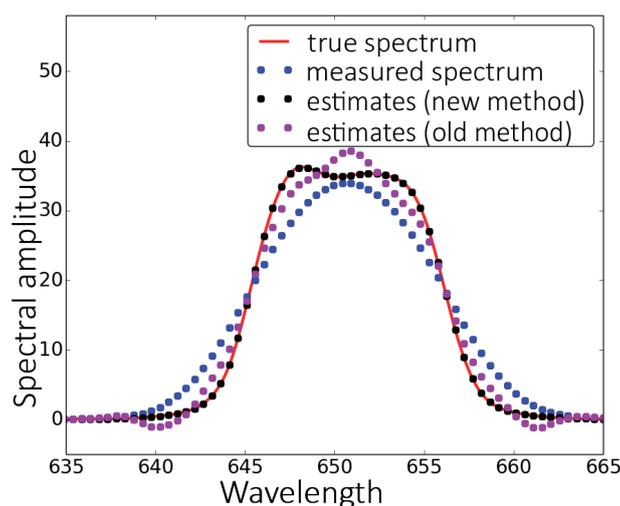
## Richardson-Lucy method with automatic termination criterion for the deconvolution of spectral distribution curves

### Especially interesting for

- illuminant calibration
- spectrometry

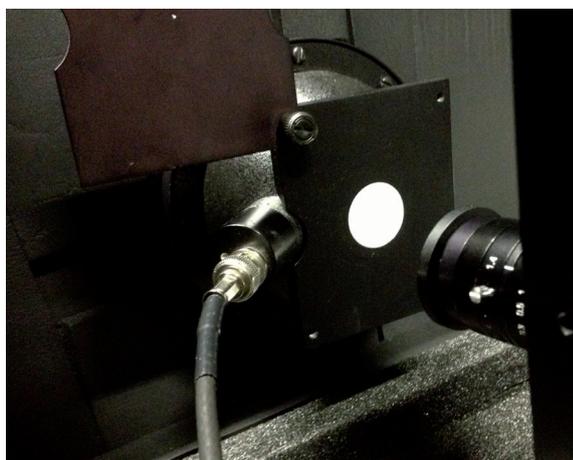
The distribution curves observed in the spectral measurements of light sources or heat radiators typically exhibit spectral distortions and a spectral resolution that is insufficient for accurate characterization. A mathematical procedure which was developed at PTB improves both these parameters.

When measuring spectral distribution curves of optical and thermal radiation sources, one of the challenges resides in the treatment of spectral distortions in the distribution curve which are caused by the measuring instrument used and are difficult to prevent. In most applications, the distribution curve observed can be mathematically modelled as the convolution of the actual spectral distribution curve of the source with the line



Simulated example of a spectral correction made with a standard method and with the new procedure.

spread function of the measuring instrument used. Determining the spectral distribution curve of the investigated source



Light source measurement (left) using a camera (right)

from the measured data then requires a deconvolution. The deconvolution of measured data by means of a transfer function of the measuring instrument is frequently needed in image and signal processing, hence, numerous methods are described in the literature.

PTB, together with the TechnoTeam Bildverarbeitung company, has made the so-called “Richardson-Lucy” method (RLM) – which originates in digital image processing – applicable to spectrometry. RLM is an iterative procedure. In each iteration, a new estimation of the distribution curve is obtained from the previous estimation. A challenge which has often been discussed in the literature when using RLM is the determination of the number of iterations. At PTB, a criterion for the selection of the number of iterations has been developed which does not require any parameters in order to determine the optimal number. For

this purpose, the change in the estimation results in the course of the iterations is mathematically assessed in order to detect specifically that iteration from which the estimated distribution curve no longer improves and noise-related distortions start.

This new procedure was tested within the scope of comprehensive simulations and of investigations on measurement data. It turned out to be extremely robust with regard to the noise and

to the resolution of the measured values of the distribution function. This makes this new procedure very well suited for practical application. Newly developed software simplifies its utilization even further.

This procedure can be applied in numerous fields of radiometry and photometry, for example, to improve measurements of both broadband spectral distribution curves (e.g. of heat radiators) and of narrowband spectral distribution curves (e.g. of LEDs) by means of array spectrometers or monochromators. ■

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### Scientific publication

S. Eichstädt, F. Schmähling, G. Wübeler, K. Anhalt, L. Bünger, U. Krüger, C. Elster: Comparison of the Richardson-Lucy method and a classical approach for spectrometer bandpass correction. *Metrologia* 50, 107–118 (2013)

# T-shaped microprobe for tactile measurements on internal threads

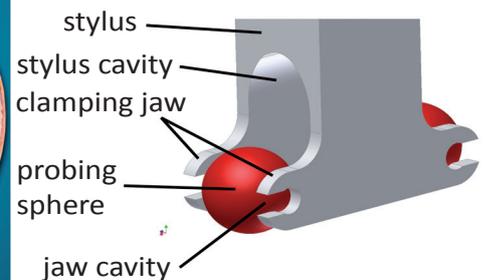
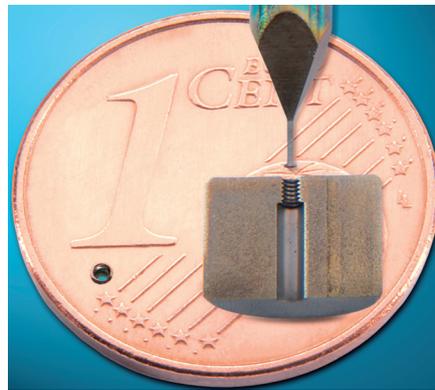
Calibration procedure for internal microstructures with gap widths of down to 150  $\mu\text{m}$

## Especially interesting for

- precision engineering
- clockmaking
- medical engineering

Measuring microstructure components is a particular challenge in precision engineering. Probes adapted to internal microthreads (such as threads with a size of M 0.7  $\times$  0.175) were previously not available. In a cooperation with partners from industry, a microprobe was developed at PTB which, based on its special T-shaped geometry, is optimized for the measurement tasks carried out on internal microthreads. A patent application has been submitted for the T-shaped microprobe.

For this new probe, the probing elements used are commercially available microspheres made of ruby with diameters of down to 110  $\mu\text{m}$  that are fixed onto a T-shaped probe stylus of hard metal. The probe stylus is manufactured by means of microwire discharge machining. Whereas small probing spheres in microprobes have often been glued to the stylus, here, a different concept has been pursued: the spheres are clamped inside the probe body. The design of the probe stylus currently allows the fitting of two probing spheres, which are kept in place



The new T-shaped microprobe with probe diameters of 110  $\mu\text{m}$  during the measurement of a microthread with a size of M 0.7  $\times$  0.175 (left) and as a schematic diagram (right)

by clamping forces only and can be exchanged.

A first validation of the procedure carried out on internal microthreads with a nominal diameter of 0.7 mm and a pitch of 0.175 mm was performed on a commercial 3D coordinate measuring machine, like those that are used to measure macroscopic components. To adapt the machine to the requirements of measurements on microcomponents, it sufficed to modify the scanning parameters such as, e.g., the probing force.

The T-shaped microprobe allows tactile measurements of internal microstructures with gap widths of down to approx. 150  $\mu\text{m}$ , as well as a reliable detection and assessment of high-precision and function-relevant internal structures such as

those that are increasingly encountered, e.g., in medical engineering. Together with a novel approach for the laminar evaluation of threads, this opens up the possibility of an extensive quality assessment. ■

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## Scientific publication

T. Krah, A. Wedmann, K. Kniel, F. Härtig:  
*Measurement and evaluation processes for inner micro structures. Proceedings 13<sup>th</sup> International Conference of the EUSPEN 1, 120–123 (2013)*

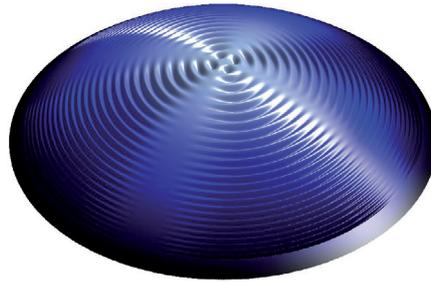
# Asphere standards

## Especially interesting for

- optics
- testing laboratories

## Licence partner wanted

Optical measurement procedures respond to slope angles and curvatures in a completely different way to tactile measurement procedures. The aim of PTB's new asphere standard is to enable comparison measurements by means of tactile and optical measurement procedures on surfaces whose form clearly deviates



Modulated sinusoidal profile on a sphere

from a sphere. These comparisons can be carried out, for example, for the determination of the lateral resolution of the measuring instrument, with a specimen whose amplitude is modulated in the

azimuthal direction by a sequence of sinusoidal profiles in radial direction. This structuring can be applied to spherical basic shapes. The artefact – which a patent has been applied for – allows numerous wavelengths to be determined with diverse amplitudes and, thus, the lateral resolution to be determined by means of only one measurement. ■

## Advantages

- *characterizing optical and tactile measurement procedures*
- *traceable calibration of measuring instruments for aspheres*
- *fast determination of the lateral resolution*

# High-frequency EEG

## Especially interesting for

- medical engineering
- electronics

## Licence partner wanted

Measuring brain waves by means of an electroencephalogram (EEG) is an established medical technique. To learn more about the function of the brain, on the one hand,



Photo: Fotolia

and to detect diagnosable pathological modifications that could previously not be detected, on the other hand, modern brain research is increasingly geared to detect low brain waves and to monitor them at high frequencies in the range of a few hundred to a few kHz. PTB's invention makes this range of medical research and application accessible. This technology allows feeds from ground loops and intrinsic thermal noise of lead electrodes to be minimized prior to the measurement. This was previously possible only to a very limited extent; in some cases, it

was necessary to resort to the differentiation of large signals by means of software. PTB's solution technically relies on a special shielding design of the analogue primary amplifier circuit, in combination with an optional impedance measurement. The system is being used in clinical research to improve diagnostic EEGs. ■

## Advantages

- *highest-sensitivity EEG measurement*
- *neuronal signals around 1 kHz become accessible*
- *simple circuit design*

# Sound protection with a bend for orchestral musicians

## Especially interesting for

- professional musicians
- manufacturers of sound protection equipment

## Licence partner wanted

An EU directive, which was passed in 2007, prescribes appropriate sound protection also for professional musicians.

Thanks to PTB's newly developed sound protection shields, orchestral

musicians can communicate perfectly during rehearsals, without having to dispense with good shielding. The attenuation partitions are shaped in such a way that they only attenuate those areas where the level of the sound coming from the neighbouring rows is high. Yet they have enough open interspaces to allow human communication. In practice, this means that the upper part of the transpar-



Photo: PTB

ent partitions is provided with a bend and a slant according to exactly dimensioned prescriptions. The acoustic surface attenuation, provided on both sides by absorbers in the lower part of the shields, prevents excessive sound levels. ■

## Advantages

- *protection of orchestral musicians against hearing damage*
- *improved mutual hearing in front of the shield*
- *flexible arrangement of the shields, e.g. in a circle*



## Contact person for questions about technology transfer

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## Awards

### Mattias Kruskopf

This employee of Department 2.5 “Semiconductor Physics and Magnetism” received the Electronics Engineering Award which honours outstanding scientific final papers. He was awarded this prize, which is endowed with 1,000 euros, for his Master's thesis entitled “Optimizing and Characterizing the Epitaxial Growth of Graphene on 6H-SiC substrates”.



## EMRP News

Project meeting of the European Metrology Research Programme (EMRP) with PTB coordination and/or significant contribution of PTB (sometimes only partly public – if you are interested, do not hesitate to contact us).

6 June 2014

### Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures (IND13 T3D)

Final Meeting, Dubrovnik, Croatia, within the scope of Euspen's 14<sup>th</sup> International Conference & Exhibition 2014.

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16–17 June 2014

### Metrology for ocean salinity and acidity (ENV05 Ocean)

Final Meeting, Berlin

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18–19 June 2014

### Metrology for ultrafast electronics and high-speed communications (IND16 Ultrafast)

Final Meeting, Prague

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25–27 June 2014

### Vacuum metrology for production environments (IND12 Vacuum)

Final Meeting, Berlin  
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27 June 2014

### High-accuracy optical clocks with trapped ions (SIB04 Ion Clock)

“Ion clock” satellite workshop at the European Frequency and Time Forum, Neuchâtel, Switzerland.

Additional information: [www.eftf-2014.ch](http://www.eftf-2014.ch)  
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### For further information on EMRP:

[www.euramet.org](http://www.euramet.org) > Research EMRP > Calls and Projects

## Dates

15–19 September 2014

### Frontiers in optical metrology

Topical meeting at the EOSAM 2014, Berlin-Adlershof

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15–19 September 2014

### International Workshop on Scatterometry at the EOSAM 2014, Berlin-Adlershof

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## PTB at trade shows

3–5 June 2014

### SENSOR+TEST 2014

International forum for sensors, metrology and testing, Nuremberg

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## Helmholtz Symposium with the awarding of the Helmholtz Prize

24 June 2014,

Haus der Wissenschaft, Braunschweig.

### Lectures: (in German)

### Röntgen – A discovery that changed the world

(Uwe Busch, Deutsches Röntgen-Museum, Remscheid)

### Research with synchrotron radiation and free-electron lasers

(Jochen R. Schneider, Deutsches Elektronen-Synchrotron (DESY) und Center for Free-Electron Laser Science (CFEL), Hamburg)

### X-rayed: X-ray beam reveals Archimedes' most ancient manuscripts

(Uwe Bergmann, SLAC National Accelerator Laboratory, Stanford)

### 4.45 pm: Ceremony

Awarding of the 2014 Helmholtz Prize



Imprint  
PTB News 1/2014, English edition, Issue May 2014, 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, Christian Lisdat, Dirk Ratschko, Mathias Richter, Hansjörg Scherer, Erika Schow, Florian Schubert, Jens Simon (responsible)  
Layout: Volker Großmann, Alberto Parra del Riego (concept)  
Translation: Cécile Charvieux (PTB Translation Office)  
Editorial Office: Press and Information Office, PTB, Bundesallee 100, D-38116 Braunschweig, phone +49 (0)531 592-3006, fax +49 (0)531 592-3008, e-mail: [ptbnews@ptb.de](mailto:ptbnews@ptb.de)



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