PTB NEWS
THE SCIENTIFIC NEWSLETTER OF PTB
2
2012

The PTB-News is the scientific newsletter of the Physikalisch-Technische Bundesanstalt (PTB). It is addressed to PTB's cooperative partners in economy, science and to all other interested readers.

Comparison of atomic clocks via the information superhighway

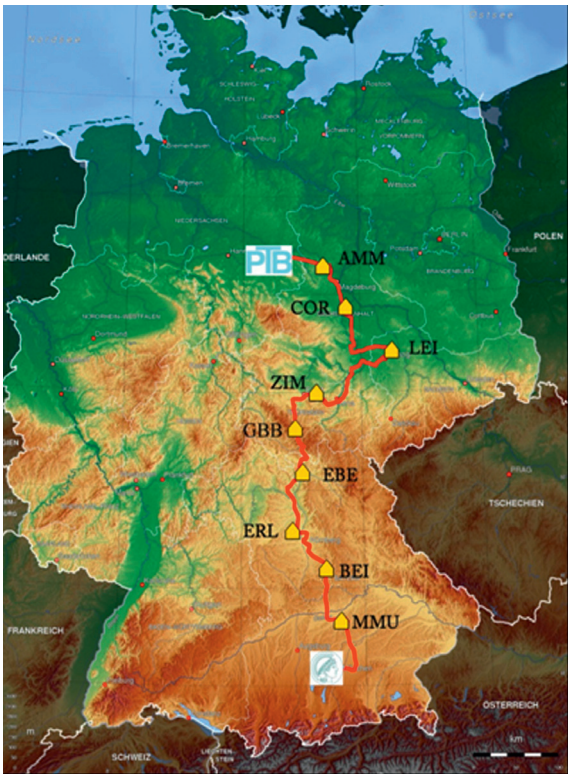
In future, optical fibre cables could connect all optical atomic clocks in Europe

Especially interesting for
- improving the time scale
- users of optical frequencies, e.g. in geodesy, astronautics and radioastronomy

In future, it will be possible to exploit the outstanding stability and accuracy of an optical atomic clock also in places other than the metrology institute where the clock is located. The prerequisite for this is for the clock to be connected to a standard optical fibre telecommunications link. This has been demonstrated on a 920 km optical fibre link between Braunschweig and Munich.

Today, optical atomic clocks are already ticking so precisely that two clocks of the latest generation differ only in the 17th place after the decimal point. Thus, they allow high-accuracy tests of fundamental theories ranging from cosmology to quantum physics. Previously, the problem was that measurements were possible only locally at very few institutes worldwide (such as, e. g., PTB). Over the last few years, PTB, the Max Planck Institute of Quantum Optics in Garching, the Institute of Quantum Optics of Leibniz University in Hanover and the Excellence Cluster QUEST, with the support of the European Space Agency (ESA), of the Deutsches Forschungsnetz (the German National Research and Education Network – DFN) and of GasLINE, a telecommunications network provider of German gas distribution companies, have been investigating how other users could benefit from the outstanding stability and accuracy of these optical clocks.

Since standard procedures for time and frequency comparisons based on satellites cannot achieve the accuracy and stability required for optical clocks, highly stable optical frequencies were transmitted via telecommunications optical fibres. In order to compensate for the attenuation of the signals due to the length of the link, optical amplifiers were installed along



920 km optical fibre link used to transmit the frequency from a PTB laser located in Braunschweig to the Max Planck Institute of Quantum Optics in Garching, near Munich.

SCIENTIFIC NEWS

TECHNOLOGY TRANSFER

MISCELLANEOUS

the way. To prevent accuracy and stability losses, it was necessary to detect and record variations of the laser frequency caused by mechanical, acoustic and thermal disturbances (e. g. due to changes in temperature, motor traffic or road works along the section). For this purpose, the receiver sends the laser light back to the emitter via the same link. After comparing the received signal with the signal sent, a correction can be stamped onto the sender, so that the signal received is undisturbed.

For the first time, it was possible to demonstrate that this is nearly perfectly possible in real time, even on a glass fibre connection of more than 900 km in length, so that the frequency of approx. 200 THz which is provided to the user deviates by less than 1/10 000 hertz from the frequency originally sent. This corresponds to a relative frequency uncertainty of less than $5 \cdot 10^{-19}$.

Optical frequencies of a quality as good as that normally provided only locally at metrology institutes can now be disseminated. Using an existing optical fibre infrastructure – as available, for example, in the national research networks – will, in future, allow the national network to be transformed into a European network that will eventually interconnect all optical clocks in Europe.

Fundamental research will be the first sector to benefit from this, for instance for determining fundamental constants with great accuracy, checking the General Theory of Relativity and for quantum electrodynamics forecasting, but also for future applications in geodesy, radioastronomy or in the aerospace industry. ■

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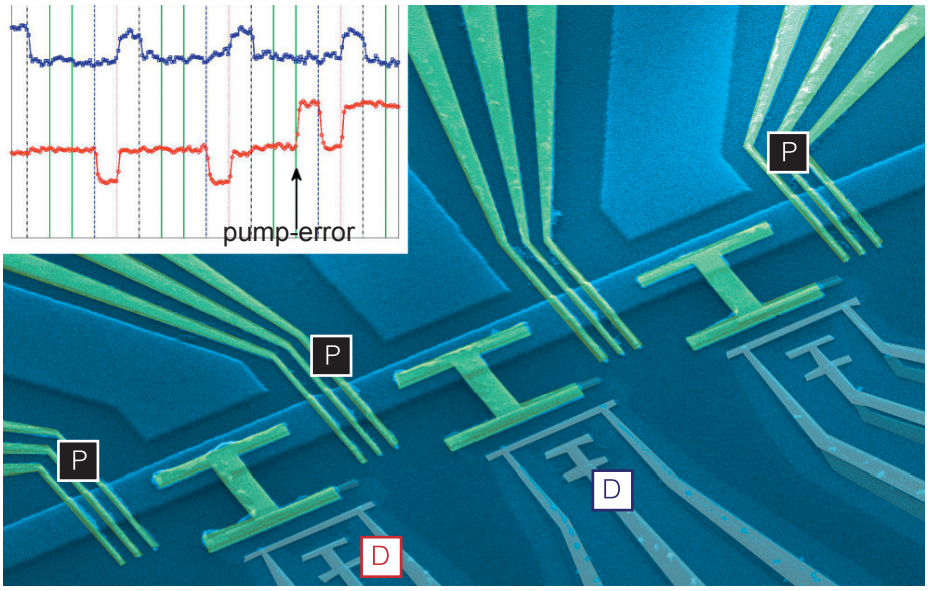
Scientific publication
Predehl, K.; Grosche, G.; Raupach, S.M.F.; Droste, S.; Terra, O.; Alnis, J.; Legero, Th.; Hänsch, T.W.; Udem, Th.; Holzwarth, R.; Schnatz, H.: A 920 km Optical Fiber Link for Frequency Metrology at the 19th Decimal Place. Science 336 (2012) 441–444

Current standard based on single electrons in the offing

Single-electron current source detects rare irregularities in current flow

Especially interesting for
- fundamentals of the system of units

A clever procedure allows rare faults in single-electron transport to be detected and, thus, accounted for. A method developed at PTB was implemented experimentally for the first time, so that the realization of an accurate current standard based on single electrons is now in the offing. This is an essential element of the re-definition of the system of units on the basis of fundamental constants where the unit of current, the ampere, is important also for the re-definition of the SI base unit, the kilogram.



Scanning electron microscope image of an array with several pumps (P) and detectors (D); this array is operated at temperatures near absolute zero. The measurement curves show the signal pattern of the detectors depicted with different colours.

In a new international system of units, fundamental constants are to play the decisive role of ubiquitous reference measurands. Voltage and resistance can be traced back to the Josephson and the von Klitzing constant, respectively, whose product is, according to theoretical predictions, equal to $2/e$, with $-e$ being the charge of an electron. If these theories are correct, also the kilogram can be traced back to electrical units and their corresponding fundamental constants by matching mechanical and electrical power in a so-called "watt balance". It is therefore essential for the whole system of units for theoretical predictions to be verified experimentally.

For this purpose, the current leading to a voltage $U \sim h/2e$ over a resistor $R \sim h/e^2$ is compared to a current $I = ef$ where electrons are moved through a single-electron pump at the frequency f. Unavoidable faults, caused by, e. g., quantum mechanical tunnel processes, however, limit the uncertainty to fractions of ppm. With the new method, such faults can, however, be detected, so that the uncertainty is decisively reduced: the cur-

rent is successively pushed through two single-electron pumps, and the charge on the island located in between is monitored. In error-free operation, the charge remains constant; in the event of a fault, it varies by one electron charge. As faults rarely occur, they can be detected even at high pump frequencies of up to several 100 MHz. Even if three pumps are used, each fault can be attributed to a certain pump thanks to correlation measurements. The current generated can thus be determined much more accurately than would be the case using only one pump.

This experiment has now been realized at PTB for the first time. Single electrons were moved through an array consisting of three active pumps (P) with two detectors (D). Both for the "red" and for the "blue" detector depicted in the figure, each electron staying on its respective island triggers a pulse which does not change the signal baseline. In the event of a fault, the baseline, however, changes, which remains detectable also at higher frequencies when pulses of single electrons are no longer resolvable.

In future, it should be possible to increase the current from the attoampere range as demonstrated here at low frequencies to the application-relevant range of several 100 pA. ■

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Scientific publication
Wulf, M.: An error accounting algorithm for electron counting experiments. arXiv:1209.1020

Absolute length measurements at temperatures down to 7 K

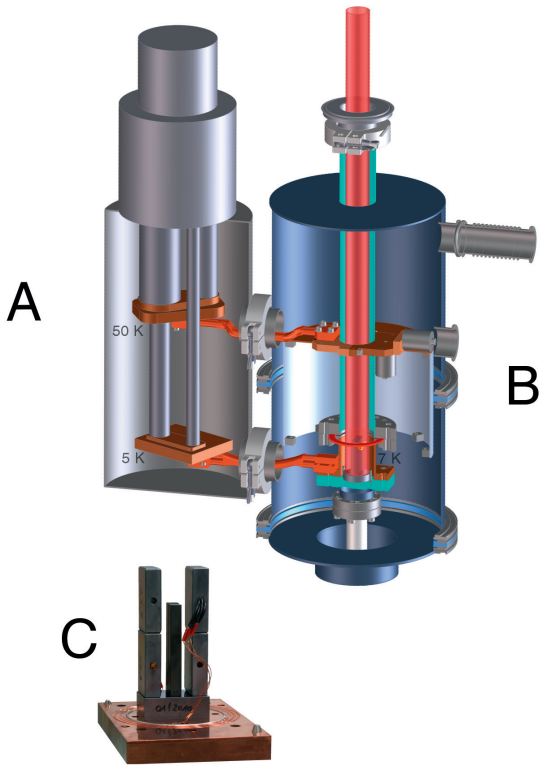
PTB Ultra Precision Interferometer (UPI) extended for use at low temperatures

Especially interesting for
- aerospace technology
- raw material producers

Within the scope of a research cooperation, PTB has succeeded in developing its Ultra Precision Interferometer (UPI) in such a way that it can now also operate at cryogenic temperatures down to 7 K and can, thus, be used to measure the thermal expansion of materials, especially of materials used in space telescopes.

PTB's Ultra Precision Interferometer consists of a Twyman-Green interferometer arrangement which is accommodated in an evacuable, temperature-regulated housing. Three lasers whose frequencies are stabilized onto the hyperfine structure transitions in iodine and rubidium, respectively, are used as light sources. As the corresponding wavelengths under vacuum conditions are very precisely known, absolute lengths of gauge-block-type (prismatic) bodies of up to 400 mm can be measured with subnanometre accuracy by means of the UPI.

In order to characterize the thermal expansion, but also the temporal stability of materials precisely, the interferometer is usually temperature-regulated as a whole, i. e. together with a test piece inside. Hereby, the useful temperature range is, however, limited to a range from 10 °C to 50 °C. In contrast, when designing modern space telescopes, the behaviour of specific materials at cryogenic temperatures is of particular interest.



Extended measurement path of the UPI. A: two-stage pulse-tube cooler, custom-built and adapted by TransMIT. B: extended measurement path for connection to the UPI. C: material measures (samples in the centre) to be measured and samples for accommodating the temperature sensors (left and right).

Within the scope of a project funded by ESA, PTB has, in cooperation with the TransMIT-Center of Adaptive Cryotechnology and Sensors, succeeded in clearly enlarging the temperature range down to cryogenic temperatures. For this purpose, the UPI was equipped with an extended measurement path which leads the light into an external container where the temperature of a test piece can be regulated separately. The specially adapted cryostat is based on a two-stage pulse-tube cooler which is connected to the sample container via flexible copper strands. Hereby, a temperature of the samples of down to 7 K is achieved.

One of the greatest challenges within the scope of this project consisted in establishing methods to evaluate non-stationary interferograms from which the absolute length of test pieces of up to 50 mm can be deter-

mined over the whole temperature range from 300 K to 7 K with 1.5 nm accuracy. The first measurements have been performed with samples made of two different materials which come into question as substrates in space telescopes. In a subsequent step, the newly attained possibilities with the ultraprecision interferometer will be exploited to define extremely accurate standards to be used as a reference for indirect measurement procedures. ■

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Scientific publication
Schödel, R.; Walkov, A.; Zenker, M.; Bartl, G.; Meeß, R.; Hagedorn, D.; Gaiser, C.; Thummes, G.; Heltzel, S.: A new ultra precision interferometer for absolute length measurements down to cryogenic temperatures. Meas. Sci. Technol. 23 (2012) 094004

Wave meets particle…

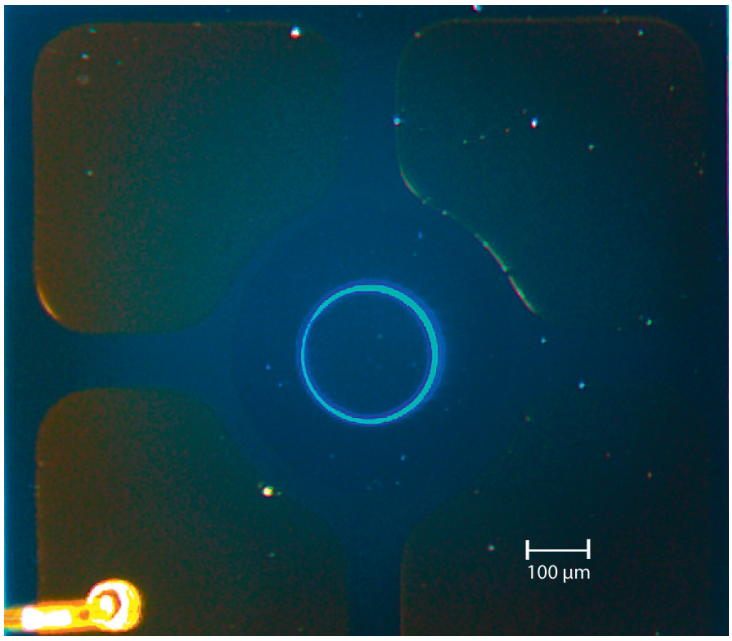
PTB now able to calibrate single-photon detectors using synchrotron radiation

Especially interesting for
- radiometry
- quantum information technology
- astronomy

With the aid of synchrotron radiation, PTB has succeeded in connecting two utterly different ranges of power of optical radiation measurement with each other – conventional radiometry at high radiant powers and the absolute measurement of single photon count rates.

At present, the question as to how two different "metrological universes" can be connected is a challenge for the quantitative measurement of electromagnetic radiation: on the one hand, conventional radiometry at high radiant powers, as is necessary, for instance, to measure solar irradiation on Earth, and on the other hand, optical measurement in the quantum universe, as is needed, e. g., to investigate single atoms or molecules.

At the electron storage ring Metrology Light Source (MLS), PTB's primary radiation source standard for calculable synchrotron radiation in radiometry, this connection has now been successfully established. When passing deflection magnets, the electrons stored inside the ring emit radiation incoherently, i. e. without influencing each other. Thus, the total radiation power can be calculated by multiplying the computable radiation for one electron within the scope of the conventional theory of electrodynamics by the number of all the electrons stored inside the ring. This simple relation between the ring current and the emitted radiation power, which can, however, strictly be applied over numerous orders of magnitude, allows, on principle, single-photon detectors to be calibrated by means of computed synchrotron radiation. Due to the optical arrangement required for focussing and for a spectral filtering of the broadband synchrotron radiation, this can, however, not be achieved with sufficient accuracy.



Microscopic image of a silicon single-photon detector. Inside the light ring, the silicon thickness has been reduced by etching in order to minimize optical losses. This is where the sensitive surface used to detect single photons is located.

This problem has now been solved by tracing the calibration of single-photon detectors back to a primary detector standard, a cryogenic electric substitution radiometer (cryogenic radiometer) – the most accurate primary standard available in radiometry. Hereby, the MLS was used as a scalable radiation source in which the number of stored electrons can be varied from 1 to 10^{11} and, thus, the radiation power can be correspondingly adjusted. Behind a spectral filter for a selected optical wavelength, the number of photons emitted per electron was first determined at approx. 10^{10} stored electrons using a photodiode which had been calibrated against the cryogenic radiometer beforehand. Then, the single-photon detector was calibrated at only a few hundred stored electrons by measuring its count rate per electron. After applying several corrections, it was then possible to determine

the quantum efficiency of the single-photon detector, tracing it back to the cryogenic radiometer, and to attain a combined measurement uncertainty of < 0.2 %, taking the photon statistics into account.

This measurement procedure is used in an enhanced form within the scope of the EMRP project "Metrology for Industrial Quantum Communication Technologies" to calibrate fibre-coupled single-photon detectors. ■

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Scientific publication
Müller, I., Klein, R.; Hollandt, J.; Ulm, G.; Werner, L.: Traceable calibration of Si avalanche photodiodes using synchrotron radiation. Metrologia 49 (2012) 152

How to take off the pressure

Tips from PTB on how to prevent damage from pressure overload in road tankers

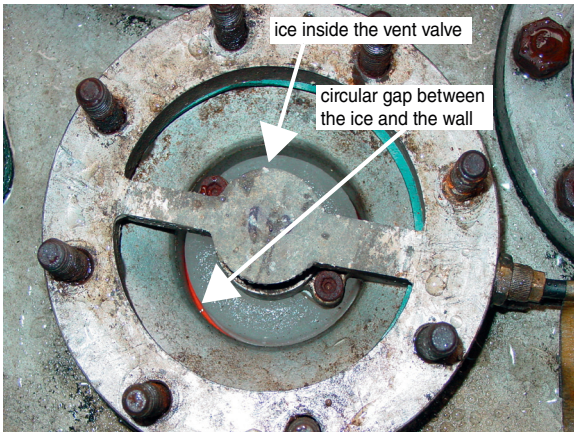
Especially interesting for
- road tanker manufacturers
- haulage contractors
- filling station operators

When filling mineral oil products into a road tanker, individual chambers of the road tanker may be damaged. The shell of the tank or the partition walls between two chambers may tear. The cause of this is presumably excessive pressure in some of the tanker chambers. PTB has investigated the causes and drawn conclusions on how to prevent such damage.

At a filling station, pursuant to legal provisions, road tankers for the transport of petrol may only be filled using the vapour recovery procedure. This means that each road tanker is equipped with a so-called "vapour-recovery hose", a separate device via which each tanker chamber can "breathe out". This ensures that the vapour/air mixture pushed out during the filling operation is returned to the vapour recovery system of the filling station, so that no excess pressure can build up inside the tanker.

Possible causes of damage due to excess pressure may be devices which are actually intended to serve for safety purposes themselves: the vent valves, which are supposed to ensure that the liquid cargo does not leak – even in the event of an accident or extreme tilt – or the flame arresters mounted in the vent valves which are supposed to prevent any flashback into the tanker chambers.

PTB determined the conditions of pressure, temperature and volume flow inside the road tanker occurring in real loading situations at filling stations. In further tests in a cold chamber, PTB investigated conditions which may lead to the freezing of the vent valve and of the flame arrester integrated into it. The results were then compared with the data obtained from real incidents.



This vent valve froze after water penetrated into the vapour recovery pipe, it is, thus, no longer operational; this can lead to inadmissible excess pressure in the tanker chamber.

As a matter of fact, some of the damage could be attributed to the freezing of the vent valves or of the flame arresters. Hereby, it is most probable that water penetrated first – either due to gate valves which had not been mounted correctly or due to cracks caused by the plexiglass disk of a flame arrester becoming brittle. In other cases, damage was caused by the fact that the wrong filling quantity was selected or that the quantity remaining inside the tanker chamber was not taken into account for the filling, but also by technical errors on the part of the filling station or in the road tanker, by operating errors or by tampering.

Measures which could help prevent such damage in future can be found at the following site: http://www.dgmk.de/downstream/publikationen/link_informationen.html (in German). The table included in these data can also be downloaded directly as an Excel table. Compliance with these information sheets is considered as a voluntary commitment on the part of all tanker operators, manufacturers, repairers and filling station operators. ■

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Scientific publication
Frobese, D.-H.; Pape, H.: Überdruck an Tankfahrzeugen. DGMK-Forschungsbericht 727, Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle e.V., Hamburg, 2011

Better comparability of blood tests

Primary measurement procedure for the quality assessment of haematological tests

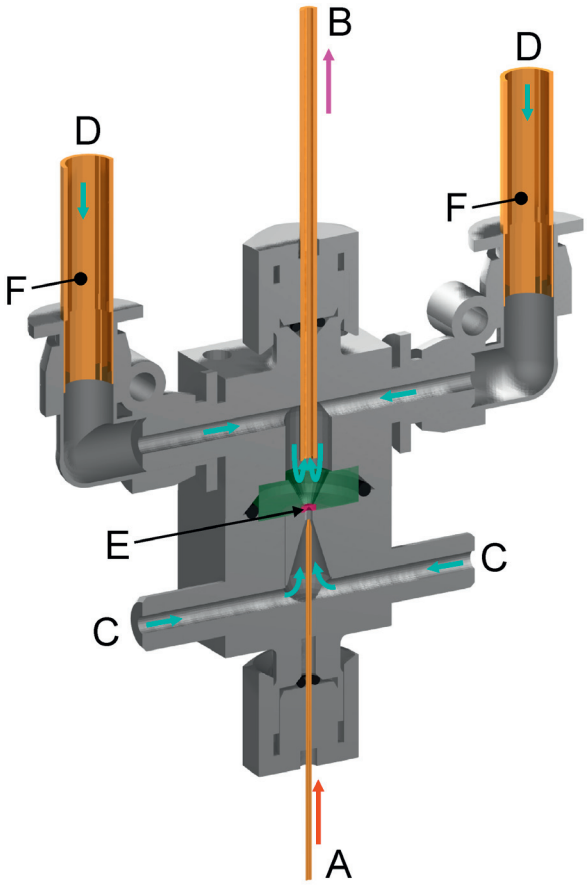
Especially interesting for
- haematological and immunological laboratories
- doctors

The primary reference measurement procedure for the determination of the concentration of red blood cells, which was developed at PTB, allows the improvement of the quality assurance of blood tests. In this way, physicians gain a more reliable basis for diagnosis and treatment.

The complete blood count (CBC) is one of the most frequently performed analytic tests in laboratory medicine. Flow cytometry is used to distinguish and count blood cell populations. According to the Medical Devices Act, participation in round robin tests for the complete blood count has been mandatory since 2002. In this way, external quality assurance to ensure the comparability of the measurement results – and, thus, patients' safety – has been established. For the evaluation of such ring trials, medical professional associations use reference measurement values from PTB as target values.

Due to the complexity of biological systems, it is crucial for many analytes to meet the requirements of a primary reference measurement procedure, i. e. for traceability to the SI units, a complete analysis of the influence quantities and interference factors as well as a detailed consideration of the measurement uncertainties. Hence, also for blood cell counting, standardized procedures potentially suited as primary reference measurement procedures are available only for few types of cells, namely erythrocytes, leukocytes and platelets. For erythrocytes, the measurement procedure developed at PTB complies with the requirements of a primary reference measurement procedure.

The measurement procedure is based on the flow-cytometric detection of cells by impedance measurements using a novel measuring sensor. It is characterized by applying a front sheath flow for hydrodynamic focussing of the blood corpuscles and a rear sheath flow. The latter prevents particles which have passed the orifice from re-circulating and, thus, prevents counting errors. Counting losses, which are due to random coincidences and depend on instrumental parameters and the properties of the sample, are taken into account by an examination of serial dilutions. The analysis of dilution series allows the determination of the reference measurement value of the erythrocyte concentration by extrapolation to vanishing volume fractions of the sample in the measurement suspension. The application of this method results in measurement uncertainties of less than 0.75 % for red blood cells being one order of magnitude below the assessment limits valid for passing the round robin tests.



Schematic representation of the measuring sensor used for the determination of reference values (A: sample inlet, B: drain capillary, C: front sheath flow, D: rear sheath flow, E: measurement orifice (Ø 40 µm or 60 µm), F: electrodes)

The researchers' next goal is to develop primary reference measurement procedures for other types of cells such as CD4-positive T-helper lymphocytes. Concentrations of these cells lying below a certain threshold level are indicative of an HIV infection. In addition, investigations are carried out to develop and validate a secondary reference measurement procedure based on relative concentration measurements. Such a secondary procedure would be applicable in routine laboratories and would allow end users to verify the quality of their own analyses. In the long run, PTB supports the introduction of internationally harmonized standards in order to ensure the cross-border comparability of medical diagnosis. ■

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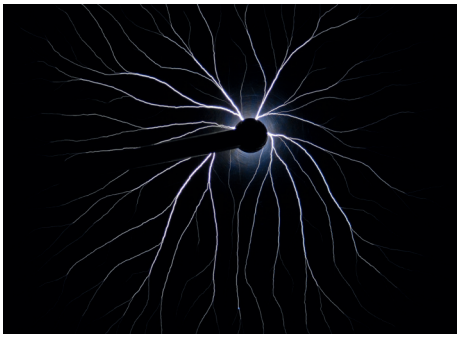
Scientific publication
Kammel, M.; Kummrow, A.; Neukammer, J.: Reference measurement procedures for the accurate determination of cell concentrations: present status and future developments.
J. Lab. Medicine 36 (2012) 25–35

Protection from electrostatic charging

Especially interesting for
- explosion protection
- plastics industry

Licence available

Thanks to a procedure which was developed at PTB and for which a patent has been applied, explosions due to the electrostatic charging of electrically insulating plastic surfaces can be prevented. Hereby, they are given a smooth, antistatic surface during the forming operation.



This procedure is applicable to plastics which are not suitable for outdoor use. Thanks to this new procedure, a greater variety of materials can be used in potentially explosive atmospheres than previously – with the costs and mechanical properties remaining virtually the same. ■

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Photomask analysis

Especially interesting for
- interferometry
- quality assurance

Licence available

Due to their stable design, Fizeau interferometers are used to determine the topography of surfaces. With a procedure, which was presented at the Optatec 2012 Trade Fair, also surfaces with different reflectivities, as occurring on lithographic masks, can be analyzed in a simple way. This procedure can also be extended to dynamic measurements. Previously, for surface analysis, the interferometer had to be calibrated against reference standards for each reflectivity. The new procedure uses a new generation of commercially available beam splitters, also called "on-axis beam splitters", which cause a separation of the polarization directions of the incident light along the optical axis. The maximum contrast is always attained, independent of the reflectivity of the test surface. The increased measurement dynamics enable measurements also in environments affected by vibrations. The patented system is of particular interest for manufacturers of interferometers as it opens up new business opportunities. ■

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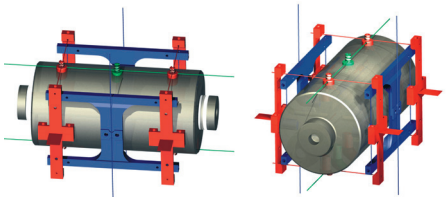
3D laser resonator mounting

Especially interesting for
- interferometry
- spectroscopy

Licence available



Producing robust lasers which emit a stable optical frequency in any orientation and at any acceleration has come a step closer. A patented, PTB-designed mounting allows high-end lasers to be operated with their highly sensitive reference resonators also in demanding environments. The mounting design employs suspending wires to fix the resonator in all three dimensions. The mounting points are located in such a way that acting forces (e. g. from vibrations) do not influence the critical resonator length that determines the reference frequency. Thus, applications are possible even under rough conditions where the laser is used as a reference source for optical clocks, for the generation of microwaves with ultra-low phase noise, or for high-resolution spectroscopy. Due to the crucial importance of the system, PTB is pursuing, in addition, the internationalization of the patent application. ■

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Awards

Gesine Grosche

The member of Department 4.3 "Quantum Optics and Unit of Length" has been given the EFTF Young Scientist Award for her "prominent contributions to several fields of frequency metro-logy associated with the dissemination of optical frequencies over optical fibres".

Nils Huntemann

The member of Department 4.4 "Time and Frequency" was presented with the "2012 IFCS Student Paper Award" by the IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society for his paper entitled "Optical clock based on the octupole transition in $^{171}Yb^{+}$".

Karsten Kossert

At the 18th ICRM Conference (International Conference on Radionuclide Metrology and its Applications) in Tsukuba, Japan, Karsten Kossert, Department 6.1 "Radioactivity", was given the JARI Enterprise Award for his "outstanding work in the radiation sciences, the nature of the research being recognised as being of a leading and challenging nature".

Tim Langer

The member of Department 3.5 "Flame Transmission Processes" was awarded the Adolf Martens Prize of BAM – Bundesanstalt für Materialforschung und -prüfung (BAM Federal Institute for Materials Research and Testing) for his paper "Electrostatic ignition risks – an improved base for assessment".

Klaus-Dieter Sommer

At this year's Measurement Science Conference in Anaheim, California, the head of Division 3 "Chemical Physics and Explosion Protection" was presented with the Woodington Award for Professionalism in Metrology "in recognition of his outstanding contributions, commitment and leadership to measurement science".

CCUPOB

The "Kompetenzzentrum Ultrapräzise Oberflächenbearbeitung" (CCUPOB) was awarded a distinction by the Parliamentary State Secretary in the Federal Ministry of Economics and Technology (BMWi), Ernst Burgbacher, for sustainable network cooperation.

Dates

13/14 December 2012:
Physics and Metrology at Low Temperature Workshop. Hermann von Helmholtz Building, Lecture Hall, PTB Berlin Institute.
Contact: Thomas Schurig.
Phone: +49 (0)30 3481-7290;
Margit Kleinsorge,
Phone: +49 (0)30 3481-7276

25/26 April 2013:
NanoScale 2013
10th Seminar on Quantitative Microscopy (QM) and 6th Seminar on Nanoscale Calibration Standards and Methods: Dimensional and Related Measurements in the Micro- and Nanometre Range. Paris, France.
Contact: Katrin Wolff.
Phone: +49 (0)531 592-5101

5/6 June 2013:
"TEMPERATUR 2013"
Procedures and instruments in the measurement of temperature and humidity
Hermann von Helmholtz Building, Lecture Hall, PTB Berlin Institute.
Contact: Jörg Hollandt,
Phone: +49 (0)30 3481-7369
Steffen Rudtsch
Phone: +49 (0)30 3481-7650

For further information
www.ptb.de > English Version > What's new > Calendar of events

Imprint
PTB-News 2/2012, English edition, Issue November 2012, ISSN 1611-163X
The PTBnews are the science newsletter of the Physikalisch-Technische Bundesanstalt (PTB). They are aimed at PTB's cooperation partners in the economy and science as well as anyone else who is interested. The PTBnews are published three times each year in a German as well as in an English edition and can be subscribed to free of charge.
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Publisher: Physikalisch-Technische Bundesanstalt (PTB), Braunschweig und Berlin
Editors: Franz Josef Ahlers, Ludger Koenders, Christian Lisdat, Dirk Ratschko, Mathias Richter, Erika Schow, Jens Simon (verantwortlich), Florian Schubert, Peter Ulbig
Layout: Volker Großmann, Alberto Parra del Riego (concept)
Translation: Cécile Charvieux (PTB-Sprachendienst/Translation Office)
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