PTB news
Metrology
Technology
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Cooperation
06.1

A great leap forward towards the optical clock

With a single Ytterbium ion trapped in an ion trap and a femtosecond comb generator, PTB has made a great step towards the realisation of an optical atomic clock. The frequency of an optical Yb^+ transition of (688 358 979 309 307.7 ± 2.2) Hz was compared over a period of several days with the frequency of a primary Cs fountain clock.

For more than half a century, caesium clocks have successfully defended their reputation as the best clocks in the world. It is difficult to enhance their accuracy any further. The most promising candidates for even more accurate and, at the same time, stable time standards are the so-called optical clocks whose transition frequencies lie in the range of visible light. Due to a frequency which is about 75,000 times higher than the Cs frequency, optical clocks can subdivide time intervals much more accurately.

In order to exploit the advantage of the higher frequency, an optical "clockwork" is needed which is able to generate the "second" from the optical frequency in a stable manner over a long period of time. Nowadays, femtosecond comb generators on the basis of ultra-short pulse lasers serve as clockworks. These lasers link the microwave region (10^8 Hz) with the optical spectral region (10^{14} Hz) via the pulse repetition rate. Similar to a ruler, the modes of a frequency comb represent an absolute measure that extends up to the optical frequencies.

PTB has now advanced a great step towards an optical atomic clock. The frequency of an optical frequency standard on the basis of a single Yb^+ ion in a Paul trap was compared over several days with that of the Cs fountain clock CSF1 and of a short-time stable hydrogen maser.

These measurements lay the foundation for the operation of an optical clock with a surpassing accuracy. They show that, nowadays, optical frequency standards with trapped ions achieve an uncertainty which is comparable to that of the most accurate caesium clock. Due to a short-term stability which is better by two orders of magnitude, for instance relative frequency variations of $1 \cdot 10^{-17}$ of a stabilised fiber laser could be detected within a measuring period of only one hour. Even with the worldwide best Cs clock, it would take an averaging period of many months.

Thus, the time is ripe to prepare for secondary realisations of the second, which, later, could possibly lead to a new definition of the second.

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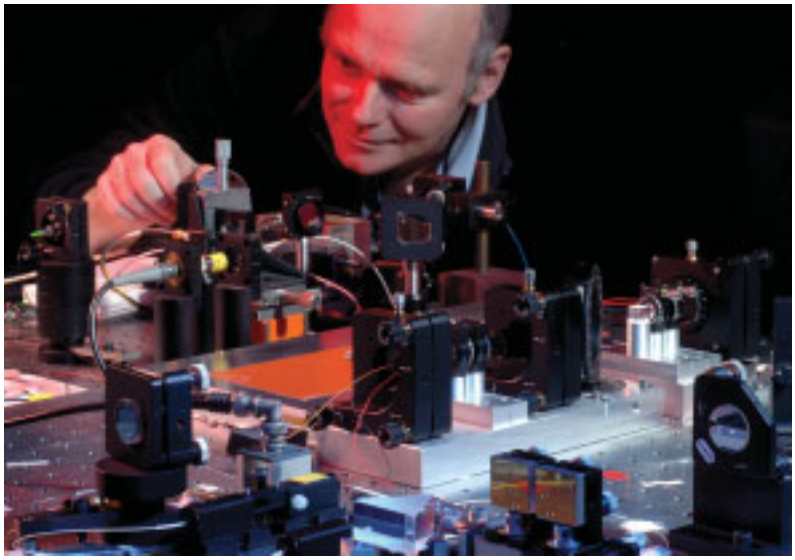

Adjustment of the femtosecond comb generator

From the quantum Hall effect to capacitance

The realisation of the unit of capacitance by means of the quantum Hall effect (QHE) has made considerable progress. Already since 1990, the QHE has served as the quantum standard for electrical resistance with direct current (DC). At PTB, a significant development has now been achieved in the measuring technique which also allows the precise measurement of the quantum Hall resistance with alternating current (AC) and provides a quantum standard for the capacitance.

A new system of physical units is planned which will consistently exploit the advantages of quantum standards and will be based solely on fundamental constants. The capacitance is thereby an important electrical quantity, not only to provide for the continuity of the old system but also for a consistency test within the new system. The link of a capacitance C with fundamental constants is based on the fact that, at a frequency ω, the AC resistance $1/(\omega C)$ can be compared with the quantum Hall resistance. The quantum Hall resistance, which only depends on fundamental constants, thus also provides a quantum standard for the capacitance.

However, precision measurements in the kHz range reveal parasitic effects in the quantum Hall element which lead to frequency- and current-dependent deviations from the DC value. By means

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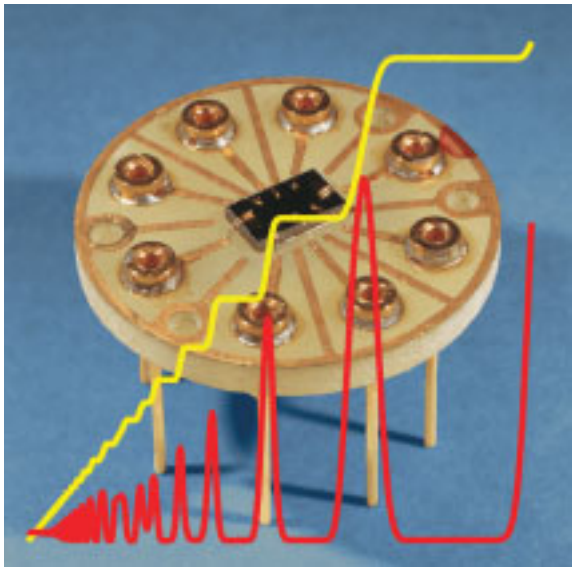
From the quantum Hall effect to capacitance *(Continued from page 1)*

of control gates which generate an AC electrical field, these deviations can be adjusted at will or compensated completely, but this adjustment is characterised by an inadmissible arbitrariness.

A further development of the complex AC measuring technique makes it now possible to measure with alternating current all those quantities which have to be checked also in the case of direct current. For the first time, the measurement of the AC longitudinal resistance provides a metrologically well-defined and sensible criterion for the adjustment of the outer alternating field: If the AC longitudinal resistance of a QHE element is balanced to zero, the AC quantum Hall resistance within an extended measurement uncertainty of $2 \cdot 10^{-8}$ ($k = 2$) becomes equal to the DC quantum Hall resistance, independent of outer influence quantities such as frequency, current and temperature.

This criterion is analogous to the internationally determined guidelines for reliable DC resistance calibrations by means of the QHE. The details for the realisation of an AC quantum standard of the capacitance shall be discussed at an international expert's meeting this year and lead to corresponding guidelines for AC.



Quantum Hall element with typical measurement curves

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Archiving of electronic documents

Within the scope of the ArchiSafe project which is supported by BundOnline 2005, fundamentals for the legally safe long-term storage of electronically signed documents over several decades (archiving) have been developed and implemented in the form of a prototype. With a presentation at the Federal Ministry of Economics and Technology (BMWi) in December 2005, the first phase of the project was successfully completed.

The development of modern administration structures is closely linked with the introduction of electronic files which, however, ensure not only the unimpeded and fast exchange of data and information between the administrative units but can also be manipulated easily and unnoticeably. Progress in eGovernment with electronic files requires that the authenticity and integrity as well as the confidentiality and completeness of the digital documents be ensured. For such an electronic document infrastructure – often in connection with signatures –, also a suitable electronic archive is required.

The development of such an archiving system is the aim of the PTB project ArchiSafe which was created within the scope of the eGovernment Initiative BundOnline 2005. ArchiSafe thereby supports the introduction of uniform standards at the federal level for the legally safe and revision-safe long-term storage (archiving) of electronic documents. An XML data exchange format for electronic documents – including meta data and signature data – has been developed under the designation "ARS" (ArchiSafe Recordkeeping Strategy). Whereas documents which have been archived in proprietary formats, e.g. Microsoft Word, and without meta data, will no longer be readable in several decades, the ARS format system ensures an improved long-term archiving of documents.

A fully functional, legally safe long-term storage has been implemented as a pilot system on the basis of a professional data processing concept which has already been published (www.archisafe.de). Hard disk storage units are used as filing media which, in comparison to the media which have been used so far for archiving (CD, DVD, magnetic tapes), enable a faster access to the archived data. When the method is used for the first time in practice at PTB, certificates of type approvals, having been created in SAP, will be stored in a long-term archive. Compulsory periods of record-keeping of at least 30 years apply for this type of document.

The certificates will be electronically signed in PDF format and then embedded in the ARS structure, together with the corresponding meta data. After a check, the object will be sent to the long-term storage which ensures the durable conservation of the documents' authenticity and integrity and carries out the signature renewal required by the Signature Ordinance. The signature renewal is carried out in accordance with the ArchiSig concept (www.archisig.de).

Unlike the archiving on WORM media (Write Once Read Multiple times), the new method offers the advantage that a subsequent deletion of filed documents, e.g. for reasons of data privacy, and the issuing of a so-called documentary evidence which can be presented in court, is possible without any problems.

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Internet portal on thermal metrology

They are omnipresent and have an influence on nearly all technical and scientific developments: the procedures and phenomena around temperature and heat. However, the detailed knowledge in this field is distributed over various places and is sometimes hardly accessible and evaluable for users. The newly founded Virtual Institute for Thermal Metrology shall remedy this problem. Its website has been created within the scope of the EU project "evitherm".

In most industrial processes, from steel production to food processing, the use of thermal technologies and metrology plays a significant role. However, many industrial users can resort to only limited knowledge in this field. The consequences are production processes which are inefficient, unnecessarily complicated and environmentally polluting. The knowledge with regard to thermal technologies is not evenly distributed and not easily accessible everywhere, which explains why industry can make only little use of it.

More than 40 project partners from 12 European countries under the auspices of the National Physical Laboratory (UK), the Laboratoire National d'Essais (France), the Istituto di Metrologia G. Colonetti (Italy), the ARC Seibersdorf (Austria) and PTB have established the Virtual Institute for Thermal Metrology (evitherm) in order to remedy this deficiency. The core of the project is the now available Internet portal in which the existing expert knowledge as well as the requirements, experience and knowledge of users have been pooled.

The aim of the Virtual Institute is to gather the information and expertise on thermal technologies and thermal metrology in one place, to link it and to evaluate it, as far as possible. Materials data and measuring techniques, standards, service and training offers, directories of suppliers of thermal equipment, etc. are components of evitherm. Special importance was attached to the fast and simple access to data and expert knowledge. The contents were compiled in a practice-oriented way, especially for users from industry. Except for the databases of thermophysical properties, the website can be used free of charge.

Website of the Virtual Institute for Thermal Metrology: www.evitherm.org

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Worldwide comparability of fluorescence measurements

Within a cooperation between PTB, BAM and two partners from industry, spectral fluorescence standards have been developed, characterised and certified, making it possible to eliminate instrument-specific influences on the fluorescence signal. Thus, fluorescence measurements can now be compared worldwide.

Fluorescence is a widely used analysis method whose applications range from environmental protection (e.g. pollutant determination) to clinical-chemical analysis (e.g. protein and DNA analysis) and the sensitive detection of chromatographic partition processes (e.g. high-performance thin-film chromatography). Fluorescence is therefore measured by means of numerous and various instrumental systems. In order to enable a mutual comparison of the results, it is necessary to detect and correct device-specific influences on the fluorescence signal. A cooperation programme between PTB, the Federal Institute of Materials Research and Testing (BAM) and the companies Gigahertz-Optik GmbH and Sigma-Aldrich GmbH, sponsored by the Federal Ministry of Economics and Technology, has achieved exactly these goals by means of a radiometric traceability chain.

The traceability chain comprises three essential elements: first, a compact, homogeneously radiating integrating sphere source. Its spectral radiance was (with virtually Lambertian emitter characteristics) reduced by several orders of magnitude compared to a tungsten strip lamp, so that its radiation properties are far better adapted to a fluorescent sample than common radiance standards.

The second element is a reference fluorometer with minimal optical imaging errors which – traced back to the radiance standard – allows the certification of fluorescence spectra with sufficiently small radiometric measurement uncertainties.

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Worldwide comparability of fluorescence measurements

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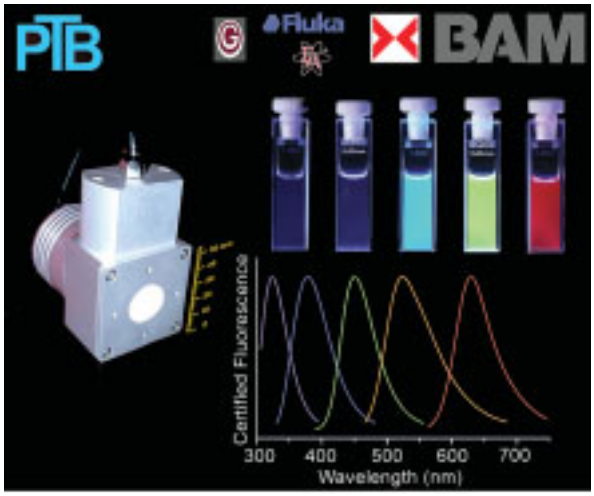
The third element of the traceability chain is the calibration set "Spectral fluorescence standards BAM-F001 – BAM-F005" whose corrected emission spectra were certified by the BAM in January 2006. These chemical transfer standards allow the user to detect and correct for the relative spectral sensitivity of the emission channel of fluorescence measuring systems under application-relevant conditions in an easy, fast and traceable way. This was confirmed by the national metrology institutes that are active in the field of fluorometry (NIST, NRC, NPL, PTB and BAM) by an international comparison of corrected fluorescence spectra, during which the new calibration set "Spectral fluorescence standards" was used as a transfer standard.



Compact integrating sphere radiator (left) and fluorescence standards with the corrected fluorescence spectra (right)

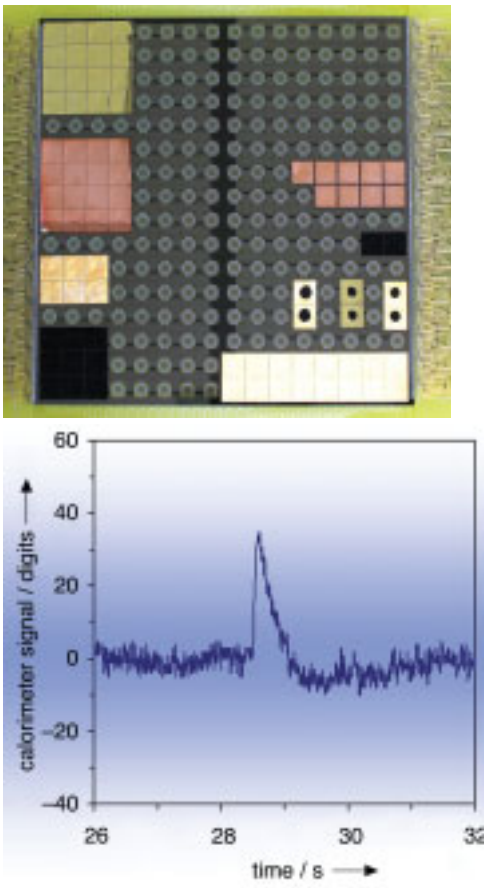
Detector for microparticles in space

An impact energy detector has been developed at PTB in order to measure the kinetic energy of fast micron-sized space particles. A sensitive calorimeter array measures the impact-related heating of the hit absorber.

Space debris increasingly endangers the unlimited usability of near-Earth space. Besides the pay loads (satellites), a large amount of microparticles has been released into space with more than 4,000 launches worldwide. These are, for example, slag residues of rocket engines or fragments generated by fuel explosions. Due to the usually high relative velocity in the case of a collision – typically 10 km/s, even particles in the micrometer regime can cause damage. In order to assess and minimise the risk, in-situ measurements provide the data base for the modelling of the particle environment.

For the development of detectors for particles in the range of a few micrometers, PTB and eta_max Space GmbH in Braunschweig have started a research collaboration. Together with further partners from Jena and Braunschweig, a two-stage detector is being developed (AIDA – Advanced Impact Detector Assembly) which will provide a clearly lower measurement uncertainty and a higher reliability compared to existing measuring procedures. The first detector stage intends to use laser-light sheets for a contact-free measurement of the velocity vector, and the second stage measures the kinetic energy of the particle impacting on a detector surface.

The development of the second detector stage has been successfully completed. The prototype of a calorimetric impact-energy detector makes use of a 16 x 16 thermopile array equipped with suitably structured metallic absorbers (e.g. made of gold foil). The detector has been successfully tested at the particle accelerator of the Max Planck Institute for Nuclear Physics in Heidelberg. The energy measuring range of such a detector can be adapted to a particular mission by scaling the absorber thickness.



For the experimental investigation of the absorber efficiency, the 16 x 16 thermopile array was equipped with different absorber materials. The diagram shows the signal of the impact of an iron particle of $1.2 \cdot 10^{-14}$ kg mass at a speed of 4.9 km/s (kinetic energy: 140 nJ).

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