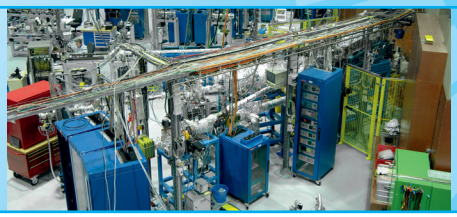
PTB news

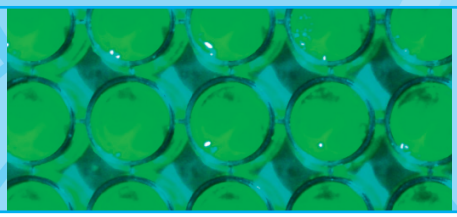
3/2011

The Science Newsletter of the Physikalisch-Technische Bundesanstalt

Long-lasting and efficient *Page 2*



Metrology Light Source ready for use *Page 4*



Analysis of ELISAs *Page 6*

Scientific news

Technology Transfer

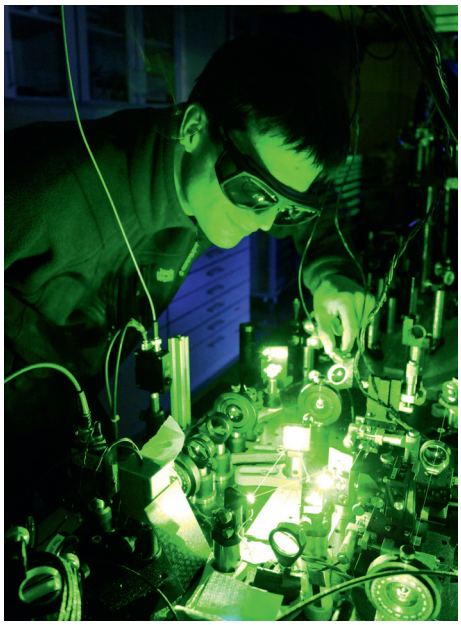
Miscellaneous

Single ions – extremely cool

A simple laser system brings a magnesium ion to a standstill

Especially interesting for
- *fundamental physics*
- *precision spectroscopy*
- *developers of optical clocks*

While looking for possible changes in the fine-structure constant, the aim is to measure the spectral lines (i. e. the inner structure) of atoms more accurately than ever before. One way of achieving this is quantum logic spectroscopy. For this purpose, physicists from the QUEST Institute at PTB and from Leibniz University Hanover now only need one single laser source – instead of complex laser arrangements – to bring a single magnesium ion in a quadrupole ion trap to a complete standstill and to determine the properties of another ion with its help.



Adjustment of the magnesium laser system

The new research results could help settle a scientific dispute – the apple of discord being the question of how to compare astronomic measurement data with laboratory references. In astronomic investigations, light is analyzed which is generated by quasars and has traversed cosmic dusts on its way down to the Earth. The elements contained in these cosmic dusts have left their characteristic "fingerprint", so to speak, which can be identified by analyzing the light. If these "fingerprints" differ from those that have been generated in the laboratory for the same elements, this possibly suggests that the fine-structure constant has changed. To date, however, it has not been possible to measure the laboratory spectra accurately enough. Scientists from QUEST (Centre for Quantum Engineering and Space-Time Research) have made an important step in this direction.

They have developed an indirect method to examine, e. g., iron or titanium ions. They couple them with other ions of the same charge by mutual repulsion of the charged particles. Together, they form a quantum-mechanical system in which one of the partners can be manipulated and investigated and which, thus, provides information about the other partner. For this, the first partner, the so-called "logic ion" (in this case, magnesium), has to be cooled down with laser light until it

reaches a standstill. Then, atomic transitions can be excited in the other partner, the "spectroscopy ion" (in this case, titanium or iron) in a targeted manner. This, in turn, provokes a recoil kick which sets both ions into motion and can be detected very sensitively on the "logic ion".

The first step of the laser cooling procedure has become much easier now. Instead of complicated systems with several laser sources on large optical tables, a novel and compact laser system has been developed which only needs a single source. To this end, the frequency of light emitted by a fibre laser is multiplied with the aid of non-linear crystals up to a wavelength of 280 nm. An opto-electronic modulator generates a spectral sideband on the light which is resonant with a transition in the magnesium ion and is used for the state preparation and laser cooling of the ions. With this arrangement, a single magnesium ion in a quadrupole ion trap was successfully cooled down to the ground state of a longitudinal mode.

In a next step, this cooling scheme will be tested for an ionic crystal consisting of a magnesium ion and a calcium ion and finally, a frequency comb will be used as a spectroscopic laser. If this can be achieved, then elements such as titanium or iron can soon be investigated with great precision in the laboratory. This would considerably contribute to unravelling the mystery of varying fundamental constants.

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Scientific publication
Hemmerling, B.; Gebert, F.; Wan, Y.; Nigg, D.; Sherstov, I.V.; Schmidt, P.O.: A single laser system for ground state cooling of $^{25}Mg^{+}$. Applied Physics B 104 (2011) 583–590

Long-lasting and efficient – without grinding teeth!

Measurement standard for quality inspection on large gears

Wind turbines are faced with tough environmental conditions. This requires particularly robust and long-lived components. With a new large gear measurement standard of PTB, the manufacturing quality of such large gears can now be tested reliably for the first time.

Especially interesting for
- *manufacturers of large gear drives*
- *manufacturers of coordinate measuring machines*

Large gears have become an indispensable part of modern mechanical engineering. Besides wind power, other industrial sectors such as shipbuilding and oil production engineering rely on the use of large gears. Gear efficiency, noise emission and service life depend decisively on the quality of the gears used. In superior accuracy classes, dimension and form tolerances below 10 µm are, for example, required for a 1 m gear.

Within the scope of an EU research project, PTB has developed a large gear measurement standard and a high-precision measuring device by which large components can be calibrated directly in industry. The special design of the measurement standard as a segment allows the measurement standard to realize a complete toothed gear of 1 m in diameter which can, however, still be calibrated on the established measuring devices at PTB. Different helix angles (0°, 10°, 20°) and hands of helix (straight, left-hand, right-hand) allow the measurement standard to be universally used. All relevant measurands were calibrated on a coordinate measuring machine using a multiple orientation measurement procedure. The results lie within the estimated measurement uncertainties of less than 5 µm.

A single segment – but the new measurement standard stands for three different, complete toothed gears of 1 m in diameter each.

The large gear measurement standard can be used for round robin comparisons. Currently, an industrial round robin comparison is in preparation; both manufacturers of measuring instruments and manufacturers of gears are to take part in it. Furthermore, the large gear measurement standard provides the basis for future accreditations in the field of large gears via the DAkkS.

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Scientific publication
Härtig, F.; Kniel, K., Wedmann, A.: Rückführung von Großverzahnungen. 4. Fachtagung Verzahnungsmesstechnik 2011 (VDI-Berichte: 2148) 225–233

One photon, one click

Calibration of single-photon detectors with nonclassical light

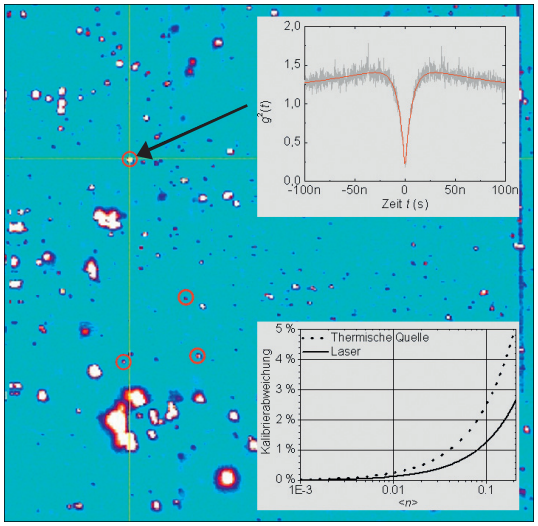
Today, single-photon sources and detectors are not used solely in experimental quantum physics, but also, for example, in medicine, biotechnology and astronomy. They play a particular role in quantum information technology (QIT) (quantum computers, quantum cryptography) which is to ensure secure data interchange in future. Due to the large number of possible applications, the need for calibrations and validations of the measuring instruments and measurement techniques required is increasing. At PTB, calibrations of single-photon detectors have been carried out for the first time with nonclassical light.

Especially interesting for
- *quantum information technology*
- *medicine*
- *biotechnology*
- *astronomy*

Single-photon sources are nonclassical light sources which emit one single photon per time interval. Within the scope of the projects qu-Candela (www.quantumcandela.org) and EPHQUAM (www.ephquam.de), single-photon sources based on the laser-induced emission of the nitrogen vacancy centres in nanocrystalline diamond have, among other things, been investigated. These light sources emit single photons; up to 10^6 such photons per second can be detected experimentally.

The emission of a single photon is proven by means of correlation measurements with a beam splitter: a single-photon detector is positioned on each of the beam splitter's outputs (Hanbury-Brown-Twiss interferometer). If single photons hit the beam splitter, they can head to either of the detectors. The probability that both detectors "click" simultaneously is, thus, zero. Hence, single-photon sources are ideal for the calibration of single-photon detectors (so-called "click detectors"), since they – contrary to classical light optical receivers – register only photons which incide singly. If, however, classical light sources are used, several photons reach the single-photon detector simultaneously; the consequence will be calibration errors. This can be demonstrated by means of numerical modelling: already at photon fluxes at which 0.1 photons on average hit the single-photon detector per detection time interval, errors > 1.2 % (laser) or > 2.5 % (thermal light) of the measured detection efficiency occur, whereby the measurement uncertainty of the investigations carried out at the moment lies at around < 1 %.

In future, spectral influences are to be investigated in detail for the determination of the relative and of the absolute detection efficiency of single-photon detectors; also alternative methods are to be used.



Confocal image of nano-diamonds. The light areas show the emissions of the centres of nitrogen discontinuities which are used as single-photon sources. Top right: The measurement of the second-order correlation function shows a drop at t = 0, which is a clear indicator of a single-photon source. Bottom right: Influence of the photon statistics of different radiation sources and of the mean number of photons on the calibration result of two single-photon detectors.

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Scientific publication
Schmunk, W.; Rodenberger, M.; Peters, S.; Hofer, H.; Kück, S.: Radiometric calibration of single photon detectors by a single photon source based on NV-centers in diamond. Journal of Modern Optics 58 (2011) 1252–1259

Metrology Light Source now ready for use

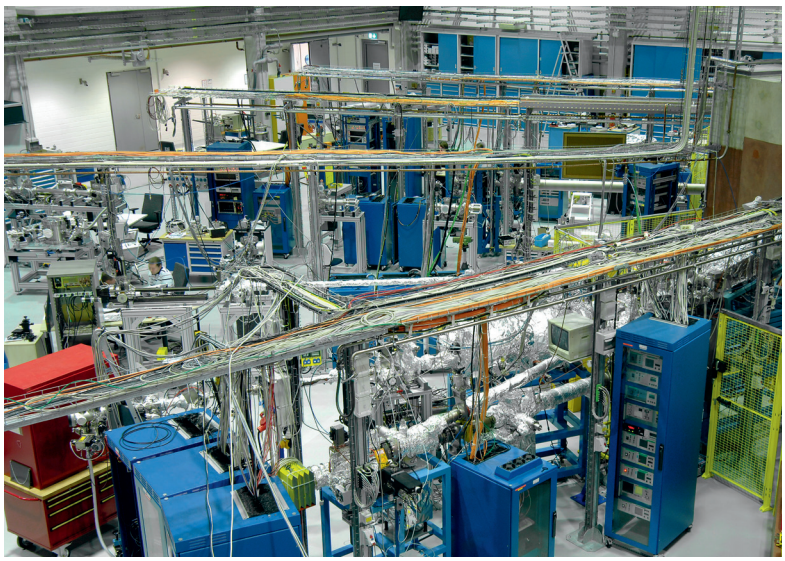
The first set of equipment for PTB's own synchrotron radiation source is completed

Especially interesting for
- *the semiconductor industry*
- *materials science*
- *astronomy*

The Metrology Light Source (MLS) is an electron storage ring which has been constructed by the former BESSY company in Berlin-Adlershof for PTB for the production and use of synchrotron radiation. It is particularly well-suited for the IR, UV, VUV and EUV spectral ranges. Since its commissioning in 2008, PTB has set up a total of 12 experimental stations on 7 beamlines for metrology with synchrotron radiation at the MLS. All of them are now ready for use.

The use of the MLS, as a primary source standard, offers unique measurement capabilities when it comes to characterizing energy-dispersive detector systems such as, e.g., spectrometers or filter radiometers, and calibrating single-

photon detectors as well as UV/VUV sources. To this end, besides a beamline for direct bending magnet radiation, also experimental stations for electron energy measurements and electron beam diagnostics have been set up. A UV/VUV experimental station for source calibration has recently been put into operation.



View into the experimental hall at the MLS: four beamlines

The UV/VUV beamline for detector calibration and reflectometry was already commissioned in 2008. It had been transferred from the nearby electron storage ring "BESSY II" to the MLS. Here, measurements are performed within the scope of services and research cooperations, for example to characterize telescopes for solar and atmospheric research. By using a long-period undulator at the MLS, high-intensity and fully polarized radiation can be generated in the spectral range from IR to the near-VUV. This provides new measurement capabilities (for example, for polarization experiments such as UV/VUV ellipsometry) which are otherwise rare in Europe.

One focus of the cooperations with industry at the MLS will be EUV lithography. Activities in this field, which had, to date, already been very exhaustive, encompass the characterization of multilayer mirrors, collector optics, reflection masks and detection systems for EUV radiation at a wavelength of 13.5 nm. Due to the transfer of the large-scale EUV reflectometer from the PTB laboratory at BESSY II to the EUV beamline at the MLS, these activities will be relocated in 2013.

Contrary to UV, VUV and EUV, in which PTB has long years of experience, the activities with regard to synchrotron radiation in the IR and THz spectral ranges, which are planned at the MLS, are all in all new. The two respective beamlines were commissioned early. For experiments in the field of microspectrometry, high-end instruments are available: a fast Fourier-Transform-IR (FTIR) spectrometer and a high-resolution IR microscope. Especially in the THz spectral range, the measurement conditions at the MLS are ideal as the MLS is the first electron storage ring to have been optimized for generating coherent THz radiation.

With the recently set-up instruments, the usage of the MLS – for radiometric purposes – is to be extended to new fields of research such as, e. g., materials analysis and materials sciences. Hereby it is planned, in cooperation with external partners, to take on new measuring technologies such as near-field microscopy, ellipsometry or electron spectroscopy.

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Scientific publication
Gottwald, A.; Klein, R.; Müller, R.; Richter, M.; Scholze, F.; Thornagel, R.; Ulm, G.: Current Capabilities at the Metrology Light Source. Metrologia 49 (2012) 146-151

Magnetic nanoswitch for thermoelectric voltages

Due to a recently discovered effect, thermoelectric voltages in nano-electronic junctions can be controlled

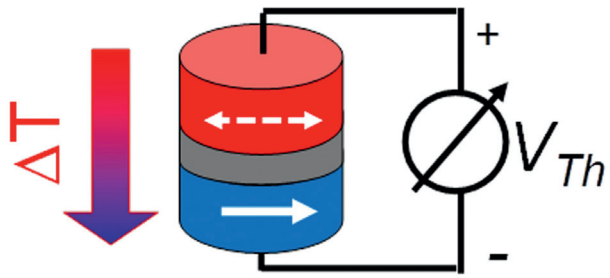
Especially interesting for
- *fundamental research*
- *magnetic data storage*
- *manufacturers of highly integrated circuits*

The heat occuring in tiny computer processors could, in future, be used to switch these processors more easily or to store data more efficiently. These are two of the several potential applications of a discovery made at PTB – the so-called thermoelectric voltage – which may well be very interesting, mainly for the use of nano-circuits, i. e. the use of small components based on magnetic tunnel structures.

Magnetic tunnel structures are already used as storage cells in non-volatile magnetic memory chips (the so-called "MRAMs" – magnetic random access memories) or as highly sensitive magnetic sensors to read out the data stored on hard disks. The new effect discovered at PTB within the scope of a research cooperation with Bielefeld University and the Singulus company could, in the future, provide a new application: monitoring and controlling thermoelectric voltages and currents in highly integrated electronic circuits.

Magnetic tunnel structures consist of two magnetic layers separated only by a thin insulation layer of approx. 1 nm – the so-called "tunnel barrier". The magnetic orientation of the two layers inside the tun-

nel structure has a great influence on its electrical properties: if the magnetic moments of the two layers are parallel to each other, then the resistance is low; if, on the contrary, they are opposed to each other, the resistance is high. The change in the resistance when switching the magnetization can amount to more than 100 %. It is therefore possible to control the electric current flowing through the magnetic tunnel structure efficiently by simply switching the magnetization.



A magnetic tunnel structure, consisting of two magnetic layers (red and blue), separated only by a thin insulation layer of approx. 1 nm (grey) – the so-called "tunnel barrier". Thermoelectric voltage V_{Th} as a result of a temperature gradient ΔT.

The work carried out at PTB now shows that, besides the electric current, also the thermal current flowing through the tunnel structure can be influenced by switching the magnetization. In their experiments, a temperature difference was generated between the two magnetic layers, and the resulting electric voltage (the so-called "thermoelectric voltage") was investigated. It turned out that the thermoelectric voltage depends on the magnetic orientation of the two layers nearly as strongly as the electric resistance. By switching the magnetization, it is thus possible to control the thermoelectric voltage and, ultimately, also the thermal current flowing through the specimen.

In future, this effect could be applied, for example, by using and converting the energy of waste heat occurring in integrated circuits in a targeted way. The discovery of this so-called "tunnel magneto thermoelectric voltage" is a milestone in the research field "spin calorics" – a field developing at a fast pace – which is currently promoted by the Deutsche Forschungsgemeinschaft (DFG) within the scope of a large-scale, 6-year priority programme.

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Scientific publication
Liebing, N.; Serrano-Guisan, S.; Rott, K.; Reiss, G.; Langer, J.; Ocker, B.; Schumacher, H.W.: Tunneling magneto power in magnetic tunnel junction nanopillars. Physical Review Letters 107 (2011) 177201

Terahertz radiation: no genotoxic effect on skin cells

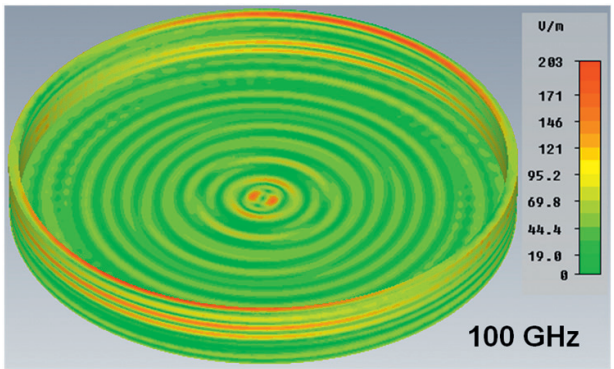
Exact dosimetry made possible for the first time by traceable measurement of the radiation density

Especially interesting for
- *safety engineering*
- *aircraft passengers and airport ground staff*

On behalf of the German Federal Office for Radiation Protection (Bundesamt für Strahlenschutz – BfS), PTB has, in collaboration with three other research institutes, studied the influence of terahertz radiation on human skin cells. Genotoxic effects could not be found.

An increasing number of commercial applications, for example body scanners at airports, use the THz frequency range between 100 GHz and a few THz – which was previously difficult to access as the radiation was difficult to detect and to generate in the first place. Although this type of radiation is not ionizing and, thus, cannot damage biological molecules directly, it had to be clarified whether this type of irradiation can have negative impacts on the growth of cells. Since THz radiation penetrates into the body by less than 1 mm, skin cells were chosen for exposure experiments.

The partners were: the Institut für Hochfrequenztechnik (Institute of High-frequency Technology) of the Technische Universität Braunschweig, the Helmholtz Centre for Infection Research in Braunschweig, and the Department of Toxicology of the University of Würzburg. The scientists exposed two different human skin cell types (HaCaT keratinocytes and primary dermal fibroblasts) under well-defined ambient conditions to continuous THz radiation at different frequencies between 100 GHz and 2.52 THz. This took place in a modified incubator at different power densities, i. e. below the safety limit, at the safety limit and slightly above the safety limit of the power density of 1 mW/cm² as is presently defined up to 300 GHz. Both the ambient conditions and the exposure power densities were recorded during the exposure. The reliability of the results was ensured by "sham exposures" (without any field) and positive controls (with a chemically induced effect) for the selected



For the first time, exact dosimetric calculations were carried out at PTB for radiation at 100 GHz. The diagram shows the field distribution in a simple sample container of plexiglass with low attenuation and at an excitation from below with a plane wave of 100 V/m field strength.

endpoints, as well as by the blinded analysis of the samples. Thanks to the SI-traceable measurements of the power density and to subsequent field calculations in the sample container, exact dosimetry was performed for the first time.

After an elaborate analysis of the three independent exposure campaigns, no genotoxic effects were detected at any of the endpoints used within the scope of the experiments. Also, neither were micronuclei detected in a corresponding test, nor could DNA fractions be found by means of comet assay. Within the scope of auxiliary experiments it was, however, noticed that the exposure of AL cells (of a human-hamster hybrid cell line) at 106 GHz leads to a disturbance of the spindle apparatus, i. e. cell division could be affected in one way or another. The project was prolonged by three months, and investigations of the relation between these disturbances of the spindle apparatus and the occurrence of micro-nuclei have begun.

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Scientific publication
Hintzsche, H.; Jastrow, C.; Kleine-Ostmann, T.; Stopper, H.; Schmid, E.; Schrader, T.: Terahertz Radiation Induces Spindle Disturbances in Human-Hamster Hybrid Cells, Rad. Res. 175 (2011) 569–574

More reliable immunological tests

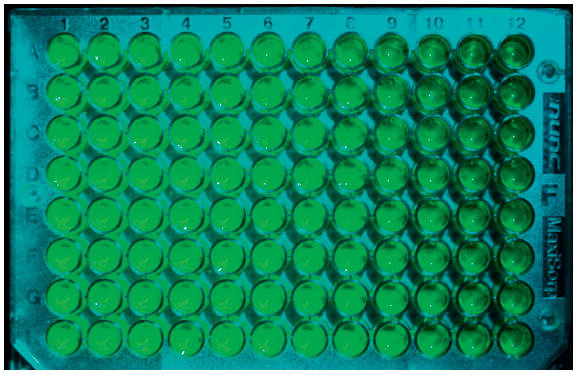
New statistical method for the analysis of ELISAs

Bindings between antibodies and antigens work according to the lock-and-key principle. This is exploited in biochemical tests, such as the immunoassay, to determine even very small substance concentrations. ELISAs (Enzyme-Linked Immunosorbent Assays), for example, may detect the presence of an infection, of hormones or drugs. At PTB, a new statistical method has been developed which makes the analysis of these measurements far more reliable.

Especially interesting for
- *medical and biochemical laboratories*
- *interlaboratory comparisons in biochemistry*

The home pregnancy test is the most well-known example of a sandwich ELISA. In general, such tests allow the detection of antigens by ‘sandwiching’ them between two antibodies. One of these antibodies is linked to an enzyme to generate a detectable signal. In the case of fluorescent sandwich ELISAs, which have recently been investigated, the estimation of the concentration is based on fluorescence measurements of a solution. To determine the relation between the measured fluorescence and the concentration, a calibration is performed for each ELISA – i. e. the same protocol steps are repeated with a solution of known concentration.

The relation between the fluorescence intensity and the concentration can be described by a statistical model. The estimation of this model (i. e. the calibration) and its application for evaluating the unknown concentration is a challenging task, as was recently demonstrated by an international comparability study using the example of an interferon: concentration estimates deviated by a factor of 2 for some laboratories. The reported measurement uncertainties do not even come close to covering these considerable differences.



Microtiter plate of a fluorescent sandwich ELISA test

At PTB, a new statistical method for the analysis of ELISAs has now been developed. This method makes use of the Bayesian approach and coherently combines the calibration of the model and the evaluation of the concentration. Moreover, the Bayesian approach enables the consideration of prior knowledge and the independent analysis of each individual ELISA. In doing so, clearly more trustworthy estimates and measurement uncertainties are provided.

As a case study, the measurements of the above-mentioned international comparability study were reanalysed, yielding corrected concentration estimates and more realistic measurement uncertainties. Contrary to the originally proposed data analysis, the consistency of the experimental methods was largely verified. The new statistical procedure now enables the reliable evaluation of measurements from fluorescent ELISAs, and thus, the reliable estimation of the concentration of interferon.

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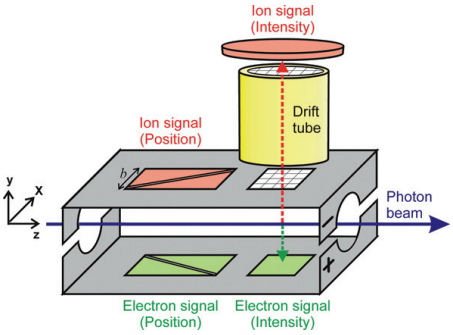
Scientific publication
Klauenberg, K.; Ebert, B.; Voigt, J.; Walzel, M.; Noble, J.E.; Knight, A.E.; Elster, C.: Bayesian analysis of an international ELISA comparability study. Clinical Chemistry and Laboratory Medicine. ISSN (Online) 1437-4331, ISSN (Print) 1434-6621

Gas detector for VUV and EUV radiation

Licence partner wanted

Especially interesting for
- *accelerator technology*
- *micro-lithography*
- *materials research*

Free-electron lasers (FEL), synchrotron radiation sources or other soft X-ray sources are of great significance to materials research and materials analysis as well as to micro-lithography. To detect the corresponding radiation, PTB has, in cooperation with the Deutsches Elektronen-Synchrotron (DESY) in Hamburg and the Ioffe Institute in St Petersburg, developed a low-pressure gas detector. It is directly connected to the ultra-high vacuum of the radiation source by differential pumping.



The rare gas, e. g. xenon, which is typically used in the detector at a pressure of 10^{-4} hPa is ionized by means of the photon radiation. Using electric fields that are perpendicular to the direction of the radiation, photoions and photoelectrons are then extracted and detected. By calibration against radiometric primary standards, and from the known cross section for photoionization, it is possible to deduce the photon intensity. Due to the low pressure of the gas, the detector is almost transparent and can, thus, be used as a monitor. Besides measuring the intensity, it is also possible to determine the position of the EUV or VUV beam accurately to a few micrometres.

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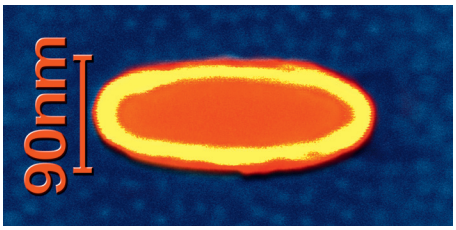
Ultrafast MRAMs

Licence partner wanted

Especially interesting for
- *manufacturers of computer chips*
- *manufacturers of mobile terminals*

One of the most important new components on the market of computer memories is called MRAMs (magnetic random access memories). Similar to the well-known Flash memories, they enable non-volatile information storage, i. e. the data remain stored in the memory upon power-off. As an important advantage over Flash memories, MRAMs offer significantly shorter



Electron-microscopic image of an MRAM storage cell

access times and an unlimited number of writing cycles. Commercial MRAMs have been on the market since 2005. They are, however, still slower than their competitors among the volatile storage media. But PTB has now invented something to change this: a special on-chip wiring, combined with the dynamic control of the magnetic components, reduces the response time from 2 ns to less than 500 ps.

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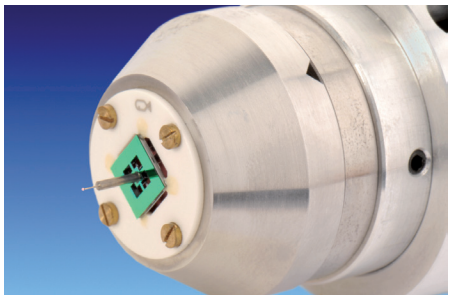
Tactile probe for micro-coordinate measuring machines

Licence partner wanted

Especially interesting for
- *micro-systems technology*
- *coordinate measuring machines*

Micro-coordinate measuring machines can measure the smallest toothed gears, injector nozzles or micro-channels for biochemical applications with measurement uncertainties clearly below 0.5 µm. The probing elements used in previous commercial systems were relatively expensive. PTB's 3D micro-probe is characterized by its nearly isotropic stiffness. It is manufactured with hybrid silicon techno-



Novel probe tip mounted on an exchangeable head

logy (also using lithographic and micromechanical technologies). Hence, a large number of probes can be produced simultaneously, which reduces the production costs. Thanks to a novel exchanging device mounted on the probe heads, the micro-probes can be exchanged very easily and are characterized by short set-up times, too.

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A new president for PTB

The post of president of PTB has been refilled. As of 1 January 2012, the physicist Prof. Dr. Joachim Ullrich has taken over this task. Joachim Ullrich left the Max-Planck-Institut für Kernphysik (Max Planck Institute for Nuclear Physics – MPIK) in Heidelberg for PTB. He took over from Prof. Dr. Ernst O. Göbel, who was in charge of the fate of PTB for over 16 years and was going to retire.

Awards

Mathias Richter und Udo Kroth

The Head of Department 7.1 "Radiometry with Synchrotron Radiation", Matthias Richter, and his staff member Udo Kroth have, together with several colleagues from DESY (Hamburg) and the Ioffe Institute (St. Petersburg), won this year's "Innovation Award on Synchrotron Radiation" which was open to scientists from all over Europe. In doing so, the Association of Friends of the Helmholtz-Zentrum für Materialien und Energie (Berlin) has recognized the development work of this research group in the field of X-ray laser diagnostics. The prize is endowed with 3000 euros and was handed over to the scientists on 1 December 2011 in Berlin.

PTB anniversary

26 March 2012: A Quantum of QI

Satellite event during the celebrations of PTB's 125th anniversary: How much Quality Infrastructure does a developing economy need to compete in global markets? How much QI is needed to enable sound consumer protection? PTB's Technical Cooperation Department, together with its partners and experts, looked for answers to these questions.

27 March 2012: Metrology, the Universe and Everything

Helmholtz Symposium on the occasion of the completion of PTB`s first 3 x 42 – 1 years. Braunschweig, Stadthalle (Civic Centre)

27 March 2012: Awarding of the Helmholtz Prize for outstanding work in metrology

Braunschweig, Stadthalle (Civic Centre)

28 March 2012: Ceremonial event for the 125th anniversary
Official reception with guests of honour, Braunschweig, Stadthalle (Civic Centre)

28 March 2012: An anniversary evening
Ceremonial event for the PTB staff members (Private function), Braunschweig, Stadthalle (Civic Centre)

14 July 2012: 125 years – precisely: Open Day
Braunschweig, PTB Campus, 15:00 – 23:00

17 October 2012: Lectures on the occasion of the 125th anniversary
Berlin, Audimax of the Technische Universität, 13:00

17 October 2012: Dedication of the renovated Observatory
Berlin, Campus of PTB

Special Anniversary Publications

The 125th anniversary is also reflected in PTB's publications of 2012. Both the PTB-Mitteilungen (the metrological journal of PTB) and the maßstäbe (the popular-science magazine of PTB) focus on special subjects. Furthermore, PTB has had its book series on the history of the institute reprinted and is making the "classical" experimental physics reference book "Praktische Physik" by Friedrich Kohlrausch available at its website.

Imprint

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