PTB news
Metrology
Technology
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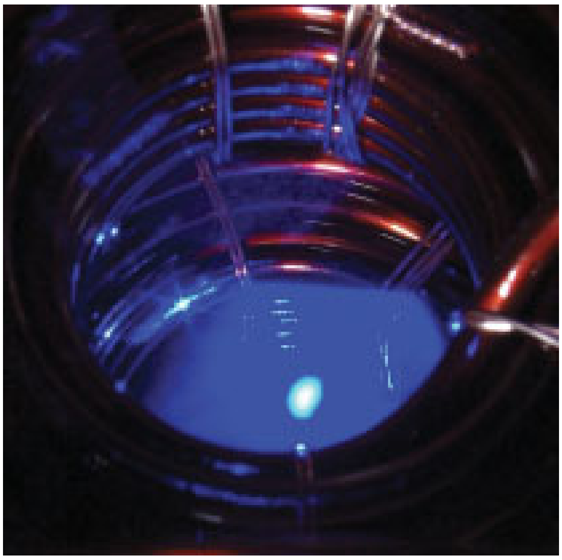
04.1

En route to an optical atomic clock

"Optical clocks" are considered as candidates for a time standard with higher stability and accuracy. Compared to the best time standard at present, – the Cesium microwave atomic clock –, uncertainties of 10^{-15} can be reached with clearly shorter averaging times. PTB has achieved a milestone en route to an all-optical atomic clock using Calcium atoms, cooled down to 10 µK, and a mode-locked femtosecond laser frequency comb.

Cooling is achieved in two steps: at first Calcium atoms are decelerated in an ultrahigh vacuum environment by resonant laser light scattering and stored in a magneto-optical trap. Then, the 657 nm transition itself (the "clock" transition) is used for cooling and to prepare a cloud of some 10^7 ultracold atoms at 10 µK. To probe the narrow line (natural line width 0.3 kHz) all laser and magnetic fields are turned off and as the atoms following gravity they are subjected to several flashes of a narrow-band laser with a line width of roughly one Hz. After determining the fraction of excited atoms the laser frequency is tuned to precisely match the resonance frequency of the atoms. Utilizing the new technology of optical frequency combs the frequency of this resonance is readily determined and traced back to the microwave frequency of the primary standard for time and frequency, the Cesium atomic clock.

With ultracold atoms a detection method can be employed which has the capability of reaching a quantum limited noise level. As the atoms in the cloud are probed simultaneously, deviations of the laser from the atomic transition frequency can be detected at very low noise levels. Thus, as a particular advantage of this optical clock, a relative uncertainty of 10^{-15} can be achieved by averaging over less than one second rather than over several hours (as is the case for Cesium clocks). In principle, the averaging time can be reduced to one tenth of a second.



Fluorescence light from a cloud of Calcium atoms during the first stage of laser cooling.

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Resonator-Solitons carry information

Optical communication systems are on the advance. In this context one goal is to achieve a completely optical – as well as parallel – processing of binary information. Technical approaches based on non-linear semiconductor optics have so far failed due to charge carrier diffusion. The latter represents no problem if one uses "spatial solitons" to transfer information.

In the field of optics solitons are primarily known as non-diverging (self-focusing) pulses in fibre optic cables. The pulses do not diverge because the particular non-linear optical properties of the fibre material compensate the dispersion. The "spatial" analogon is when the non-linearity balances the diffraction. Such "spatial" solitons have the properties of bi-stability and transversal mobility. Thus they can be used as optical carriers of information but also as inertia-free probes for microscopy. Whereas such spatial solitons were hitherto demonstrated in slow non-linear materials only, PTB has now successfully created spatial solitons in semiconductor microwave resonators.

High switching velocities and favourable integration with other semiconductor components are now feasible. One application which especially exploits the mobility of the solitons is a "photonic buffer". The latter is generally needed to deal with problems that require temporary storage ("buffering") of optical information, particularly, however, to synchronize optical communication networks and for optical "package" transportation.

The figure depicts the first step in making a "photonic buffer". A quasi-one-dimensional region

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Resonator-Solitons carry information

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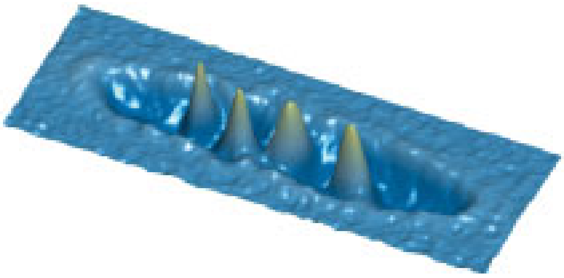
of a semiconductor cavity resonator is irradiated. On the left-hand side solitons are written successively. They drift with a varible velocity to the right-hand side where they are read out. The drift velocity of the solitons determines the buffer time of the optical information. It can be varied continuously via light field parameters or through an applied electrical field.

The power needed to maintain a soliton in passive resonators is ca. 1 mW, still quite high. By employing an active resonator (VCSEL, vertical cavity surface emitting laser) the power has already been reduced to 80 µW. Even 10 µW appear feasible. This opens the door for two-dimensional applications such as switching matrices. This work was carried out in joint cooperation with further research groups in Germany, France, and the United Kingdom. It was supported by the ESPRIT Programme of the European Union.



Four Solitons drift in a "channel" defined by light. The soliton diameters are ca. 5 µm.

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Industrial computed tomography: increased accuracy

Industrial computed tomography facilities are increasingly applied for non-destructive measurements of the geometry of components. Within an industrial project PTB reduced the occurring measurement deviations.

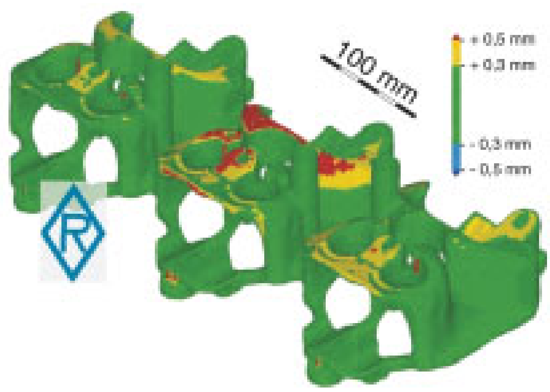
As a method computed tomography (CT) with x-rays was originally developed for medical applications. However, it has also been used for non-destructive error detection for a long time. Nowadays, industrial CT-facilities are also applied for dimensional measurements with high point densities, e.g. to determine wall thicknesses or for comparisons with CAD data.

In particular, CT can determine inner geometries, which were accessible classically only after object segmentation. However, complex influence factors cause measurement errors which were hard to quantify so far.

The dimensional measurement properties of CT have been assessed in cooperation with a medium-sized foundry company.

Test bodies made of aluminium, ceramics, granite and aluminium cast parts (e.g.: cylinder heads of max. 200 mm penetrated thickness) were calibrated tactilely with coordinate measurement machines and subsequently investigated on the 450 kV CT-facility of the industrial partner. Systematic measurement deviations are corrected now with the procedure resulting from the experimental tests. For single measurement points the measurement deviations already could be reduced to 0.1 mm. Thus, for specific applications CT is now capable to substitute measurements on coordinate measurement machines. Here enhanced applications of CT are foreseeable.

In a new project by the German Federal Ministry for Commerce and Labour (BMWA) PTB is aiming at increasing the accuracy of CT-facilities in cooperation with ten German industrial firms and the German Federal Institute for Materials Research and Testing (BAM). On one hand CT-facilities with standard x-ray tubes for measuring large components are under investigation. On the other hand CT facilities are examined which use microfocus-x-ray tubes of up to 225 kV and smallest volume-elements (voxels) of currently $(3\ \mu m)^3$ to measure small components with aspired uncertainties in the µm range.



Contour of a water jacket of a cylinder head. The colour-coded surface represents the deviations from the nominal contour in mm. (Source: Fa. Rautenbach, Wernigerode)

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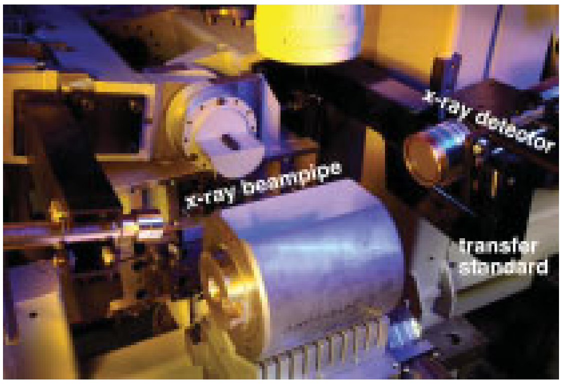
Orientation of silicon wafers can now be calibrated

A new procedure – developed at PTB – makes it now possible to reference the crystal orientation of silicon single crystals to industry. This will facilitate the alignment of wafers and reduce production costs.

In electronic device production it is indispensable to know the precise orientation of the crystal planes of a silicon wafer. Chip producers therefore require certified wafers with such a declaration. To this end producers mark the wafers with so-called "flats" or V-grooves. The angular position of the marks is to be given in reference to a crystal plane with a measurement uncertainty of less than a few angular minutes.

As a result of its research work with silicon single crystals PTB has developed a procedure and a transfer standard to calibrate these off-angles. The transfer standard is a cylindrically polished silicon single-crystal of roughly 20 cm length. A flat mirror (flat) parallel to the (100) crystal plane was polished on the standard's shell surface and a V-groove was milled on the opposite side. In the future the groove will serve to align the wafers for the process of chip production. The cost-intensive "flat"-method would no longer be necessary. Measuring the V-groove in reference to the crystal plane occurs in two steps. First, the position of the groove is determined with respect to the flat mirror by a coordinate measuring machine. Then, the angular position of the mirror with respect to the crystal plane is measured by x-ray diffraction in the PTB crystal-orientation apparatus (see PTBnews 01.3). The achieved measurement uncertainty lies in range of a few angular seconds and meets the technical requirements specified for the transfer standard.



The new transfer standard with polished mirror (Flat) inside PTB's Crystal-Orientation Apparatus

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Calibrating dynamic shock load

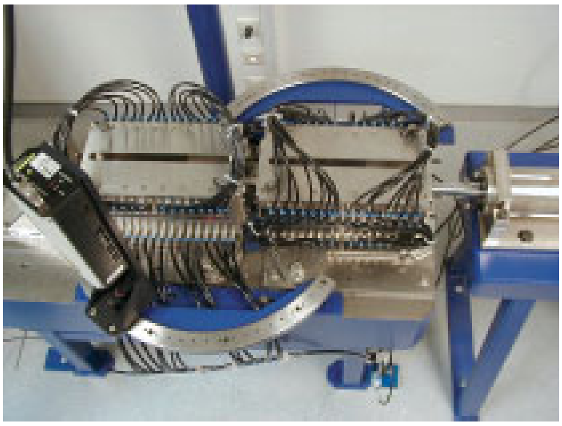
PTB has developed and constructed a new impact-force-standard measuring device. For the first time force transducers subjected to shock can now be calibrated dynamically with the new equipment. The acceleration of two masses striking each other is determined by means of a laser-Doppler-interferometer.

Although dynamical force measurements are becoming increasingly important in industry (e.g.: in crash tests) it is still general practice to carry out static calibrations on force transducers even if they are to be used for dynamic measurements. In consequence, the actual measurement uncertainties are not precisely known.

In addition to the established static calibration PTB has developed an impact-force-standard measuring device, which describes the measurand "force" by principle of inertial mass. The force is traced backed to the SI units through measurements of mass and acceleration.

The apparatus utilises two cuboid-shaped mass-bodies of roughly 10 kg, guided on air-bearings for low friction. A force transducer is connected between them and they are brought to collision. The velocity of the mass-bodies is measured without contact by a laser-Doppler-interferometer (vibrometer). Numerical differentiation yields the desired time-dependent acceleration.

The new calibrating facility for shock forces of up to 20 kN is now in commissioning. First tests demonstrated a force amplitude reproducibility better than 0.1%. It is now for the first time possible to investigate the dynamic behaviour of force transducers under well-characterized shock loading.


The new impact-force-standard measuring device. The force transducer is mounted between the two bodies.

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Certification body for measuring instruments

The European Measuring Instruments Directive (MID) 2004/22/EG, published 31 March 2004, will bring considerable changes for legal metrology. To prepare for these changes a new certification body has started its operations at PTB.

According to the current German metrology and verification act a measuring instrument subject to legal control may only be placed on the market and put into use if the manufacturer has gained the approval for the instrument type and each individual serial instrument has been verified. Within the next two years MID will be put into national legislation by a new metrology act. Then a manufacturer will have the choice between different conformity assessment procedures. The role of the state as testing and certifying body will be taken over by notified bodies. The latter will be appointed by the responsible national ministries for certification of instruments and assessment of quality management systems.

PTB is preparing itself to act as a notified body for conformity assessment according to modules B (type examination), D (quality assurance in production) and H1 (design examination and quality assurance in development and production) for all kinds of measuring instruments concerned by MID.

In order to comply with the normative requirements of the notification – in particular, to separate testing and certification – PTB has installed a central certification body for measuring instruments. Technical tests will continue to be carried out in decentralised manner. Certification, including issuing the type approval certificate will be carried out by independent certification representatives. The representatives will be professionally competent and experienced and will act temporarily in the certification body.

Since the beginning of this year the certification body is already issuing type approval certificates according to the applicable metrology and verification act. As soon as the internal procedures are routine the aforementioned conformity assessment procedures will be introduced, so that manufacturers can obtain the necessary certificates from PTB well in time to place on the market new products as soon as MID has been implemented into national law.

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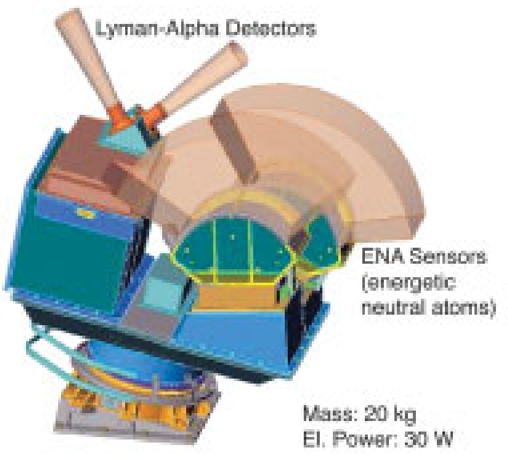
NASA photodetectors calibrated by PTB

The extremely sensitive Lyman-alpha-photodetectors for NASA's TWINS mission (Two Wide-angle Imaging Neutral-atom Spectrometers) were calibrated at PTB's radiometry laboratory at the Berlin synchrotron radiation facility BESSY in co-operation with the University of Bonn.

The TWINS Mission is to provide the first three-dimensional image of the plasma surrounding the Earth. Therefore different detector systems – payloads on two SMEX-satellites (Small Explorer) – are to picture the Earth's magnetosphere stereoscopically from two points in different orbits around the Earth. In order to create a model of the hydrogen geocorona, it is also necessary to register the Lyman-alpha intensity distribution of the terrestrial hydrogen exosphere.

For this purpose, two detector systems were developed by the Institute of Astrophysics and Extraterrestrial Research at the University of Bonn. The detectors are extremely sensitive in the wavelength region around 122 nm, so that the tests and calibrations at PTB's radiometry laboratory at BESSY had to be carried out in the picowatt radiant power range (10^{-12} Watt). This required PTB's scale for spectral sensitivity in the UV and vacuum-UV spectral region to be expanded by five orders of magnitude to lower radiation power levels by exploiting the possibility of adjusting the beam current in the BESSY storage ring very precisely. Take-off for both satellites is scheduled for 2004/2005.



The TWINS instrumentation consists of the Lyman-alpha detectors calibrated by PTB and detectors for energetic neutral atoms.

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