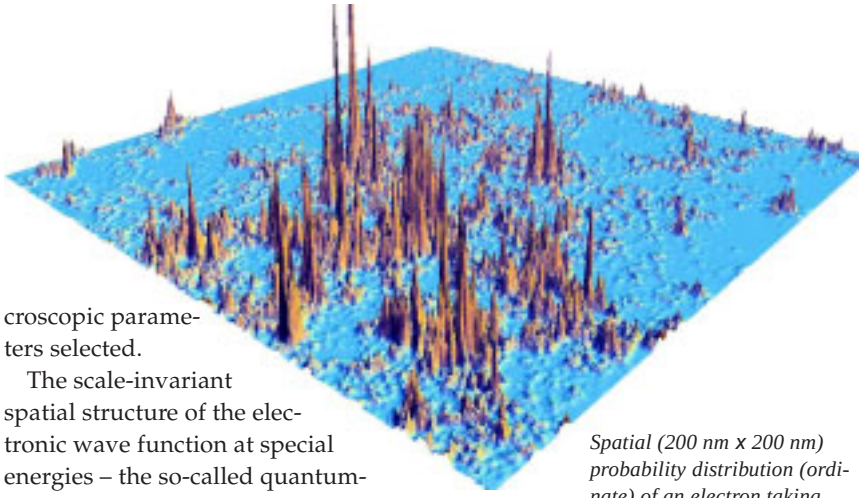
PTB news
Metrology
Technology
Services
Cooperation
06.2

Universal conductance at quantum-critical points

A quantitative correlation with the multifractal electronic eigenstates could be established for the dissipative electric transport in quantum Hall systems. Quantum-mechanical model calculations have led to a universal conductance value.

At PTB, the electrical unit of resistance, the ohm, is realized with high precision by means of the quantum Hall effect. An electric current is driven through the interface of a sample made of semiconductor layers that, at low temperatures, is exposed to a strong magnetic field. The ratio of the current flowing through the samples to the Hall voltage measured across the current direction defines the quantized Hall resistance. This quantity is determined only by the ratio of Planck's constant h and the elementary charge e, as well as by an integral number. Presently, the conductance detected parallel to the current flow is of no importance for metrological applications, but it is essential for the understanding of the quantum Hall effect, as well as for the general theory of quantum phase transitions.

Up to now, $^1/_2 e^2/h$ has been predicted for the maxima of the longitudinal conductivity that occur only at the steps of quantized Hall plateaus, which was also confirmed by earlier experiments. However, new quantum-mechanical model calculations have furnished a universal value of 0.6 e^2/h for both the two-point conductance and the longitudinal conductivity, and this independent of the microscopic parameters selected.



Spatial (200 nm x 200 nm) probability distribution (ordinate) of an electron taking part in current transport in the case of the quantum Hall effect. The self-similar structure of the fractal landscape determines the universal conductance.

The scale-invariant spatial structure of the electronic wave function at special energies – the so-called quantum-critical points – could be determined as the cause of this unexpected discrepancy. Although their multifractal properties have been known for some time already, it is only now that a quantitative relation between the experimentally accessible conductance and the theoretically calculated fractal dimensions could be established. This new finding has also been confirmed for the critical conductance at the metal-insulator transition of two-dimensional disordered systems with spin-orbit interaction. These are presently being investigated more intensively in relation with spintronic applications. The link between critical conductance and fractal dimensions appears to be a universal property of quantum phase transitions.

Further information can be obtained from
L. Schweitzer
phone: +49 531 592-81 24,
e-mail:
ludwig.schweitzer@ptb.de

Dynamic weighing of heat quantities

Industrial flow rate measurements, e.g. for district heating and cooling supply, are usually traced back to weighings and time determinations. At PTB's new volume-flow standard measuring facilty for heating and cooling meters, a dynamic weighing method has been developed for volume flow in the range below 200 m³/h, which is particularly important for industrial applications. In comparison to the static weighing procedures commonly used up to now, the technical input and the measurement time required by this new method are significantly lower. For heat quantity measurements, the temperature must in addition be stabilized and measured precisely.

For static weighing, the volume flow, which has been regulated to a constant flowrate and a constant temperature, is led into the weighing tank for a defined time by means of a complex diverter, and the quantity is weighed. Since large volume flows must be diverted with an uncertainty of milliseconds, the uncertainty contribution of the time measurement dominates the total measurement uncertainty of the facility. Furthermore, such selection devices are technically extremely complex, prone to defects and – depending on the type – not non-reactive.

In the dynamic weighing procedure, the water flows through the weighing tank without a diverter. Thereby, the weighing instrument is pre-loaded with standard weights. The measurement starts as soon as a pre-selected initial level is reached. In the course of the measurement the standard weights are removed from the weighing instrument while the tank is increasingly filled. The measurement is completed and the filling time is determined when the initial trigger threshold is reached again. At this

Continued on page 2

Dynamic weighing of heat quantities *(Continued fom page 1)*

moment, the mass of the removed standard weights is exactly balanced out by the mass of the fluid flowed in. The advantages of this method of measurement are its technical simplicity, its non-reactiveness to the volume flow and the significant time saving, which, depending on the flow rate, can reach a factor of up to 2. Since the weighing instrument is used at one distinct point only, it is not necessary to know its characteristic curve. The vibrations occurring during the filling of the weighing tank could be brought under control.

Equivalence of the two methods could be proved in a volume flow range of up to 180 m^3/h. At a water temperature of 50 °C, for instance, an agreement of 0.04 % resulted, which lies within the relative expanded overall measurement uncertainty of the facility. Thus, a new and more economical method of volume flow determination for heat and cold meters is available for industrial use.

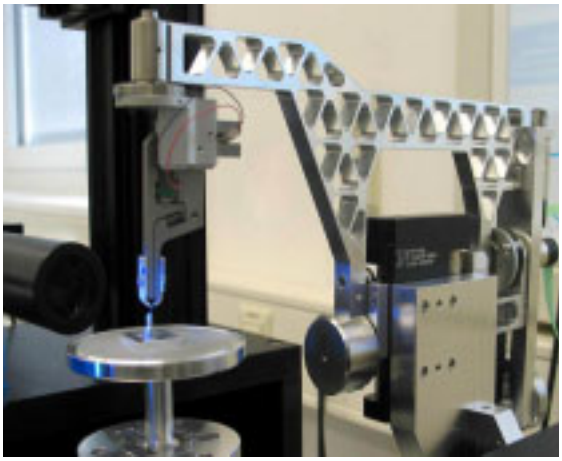
Weighing instrument for gravimetric flowrate determination; max. load: 20 t, measurement uncertainty: 100 g.

Further information can be obtained from Th. Lederer, phone: +49 30 34 81-72 30, e-mail: thomas.lederer@ptb.de

Micro-assembling robot

The micro-assembly of miniaturized sensors and standards in metrological facilities is a new challenge to PTB's Scientific Instrumentation Department. For this purpose, a high-precision multi-purpose robot – for which a patent has been applied for – has been developed which can position micro-objects with a reproducibility smaller than 1 µm with six degrees of freedom and large angular motion.

Commercially available micro-assembly devices are usually highly specialized. Their kinematics has only a small number of degrees of freedom or it can carry out only restricted angular motions of the tool towards the object within the workspace. The observation and control of the device with the aid of a camera often turns out to be difficult because the camera must be carried along or it is hardly possible to integrate it into the mechanical set-up.



Due to the special arrangement of its axes, the newly developed robot allows movements of the tool towards the object with 6 degrees of freedom in a cylindrical workspace of 60 mm in diameter and 25 mm in height to be performed. The possible angular motions are – depending on the axis of rotation – approx. ±90° or ±180° respectively. The increment for linear movements is 0.1 µm and smaller than 1′ for angular motions. High-precision positioning of micro-objects, which can additionally be oriented in large areas, is now possible.

The small objects are manipulated by mechanical and suction grippers that have also been self-developed. It is thereby possible to follow the process thanks to a nearly unrestricted large-scale and high-resolution imaging from two vertical projections without any risk of collision (pixel size approx. 1 μm^2). The whole facility is controlled by a PC-based system in a universal programming language. Significant movement and grip functions can be easily operated by means of a joystick. A universally usable robotics is thus available for the different micro-assembly tasks and with direct result control and inspection.

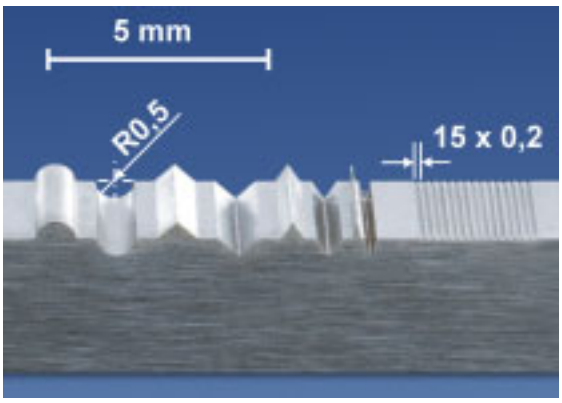
An interesting application of the new robot was, for instance, the assembly of stylus tips for scanning probe microscopy. Its use in high-vacuum for SEM observation of assembly processes is imminent.

Further information can be obtained from R. Meeß, phone: +49 531 592-55 60 , e-mail: rudolf.meess@ptb.de

Small world: micro-artifacts

The measurement of micro-components is a new metrological challenge in modern production technology. For the assessment of the measuring systems used, PTB has developed micro-artifacts for which – depending on the measuring method – a calibration uncertainty of 0.5 µm has so far been achieved for distances and radii.

Miniaturization in technology leads to components with decreasing size such as e.g. micro-gears and micro-optical components with features smaller than 0.5 mm down to 1 µm. To measure micro-components today, optical, tactile and x-ray-tomographic micro-sensors are used. Their verification should be carried out in accordance with accepted procedures of coordinate measuring technology (ISO 10360, VDI/VDE 2617). These procedures utilize artifacts. Micro-artifacts with suitable dimensions have so far not been available.



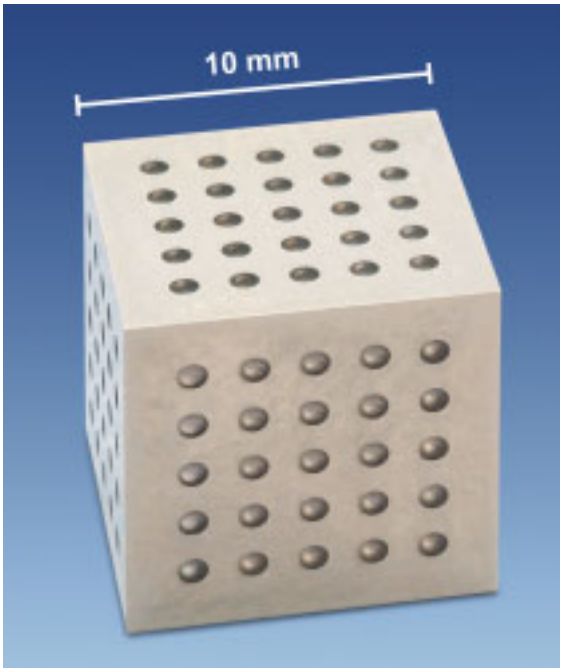
Micro-contour standard of stainless steel (detail). The standard is manufactured by wire-cut EDM and shows different radii, angles and distances. It is commercially available.

PTB has therefore developed different micro-artifacts which have "cooperative" surfaces for tactile and optical probing or can be measured by x-ray computed tomography due to their volume properties (e.g. x-ray absorption). For the manufacture of these micro-artifacts, different manufacturing processes, such as wire-cut or die-sinking EDM or diamond turning were used. In some cases, the surfaces had to be subsequently structured, e.g. by laser processing, to achieve metrologically suitable surfaces.

Comparison measurements with different tactile and optical microsensors on a micro-contour standard showed agreements of sometimes more than 1 µm for distances and radii. With the development of the micro-artifacts and the corresponding calibration procedures, a decisive step towards the qualified comparison of different sensors and their traceability in the microrange has been made. In some cases, the artifacts could be transferred to industry within the scope of cooperative projects.

A future task will be a further miniaturization of the artifacts and structures, as well as the reduction of the calibration uncertainty in order to meet the ever growing demands on the verification of more and more accurate measuring devices for artifacts that are becoming smaller and smaller. Calibration uncertainties of 0.1 µm and better are aimed at for tactile and optical measurements.

Further information can be obtained from M. Neugebauer, phone: +49 531 592-52 11, e-mail: michael.neugebauer@ptb.de



Micro-cube made of titanium with spherical calottes. The cube was produced by means of wire-cut and die-sinking EDM and has on three of its sides 5 x 5 spherical calottes of 0.4 mm in radius.

High-precision chemical analysis: an optical reference procedure

A novel combination of surface-enhanced Raman scattering and isotope-labelled standards allows a precise and sensitive measurement of substance concentration to be performed by optical spectroscopy. This method makes, for instance, a molecule-specific concentration determination of diagnostic markers in biological substances possible, which are, for example, as complex as blood serum.

Optical spectroscopy methods are widespread in the field of organic and biochemical analysis. Molecule-specific methods (IR, Raman) even provide a "fingerprint" of the sample investigated but are often not sufficiently sensitive. An outstanding signal amplification is, however, possible by means of surface-enhanced Raman scattering (SERS). It is achieved by adding metallic nanoparticles to the analyte. Up to now, however, it has not been possible to make metrological use of this advantage since the measurements were not sufficiently reproducible. This problem could now be solved by a method based on the principle of the so-called isotope dilution.

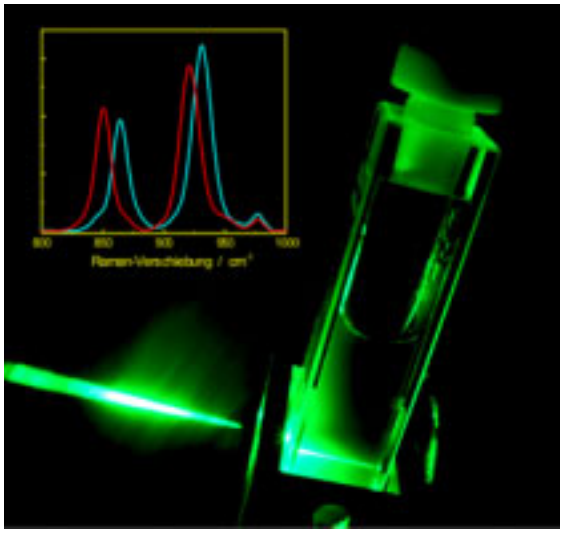
To precisely determine the analyte concentration, a known quantity of a compound that is chemically

Continued on page 4

Further information can be obtained from R. Stosch, phone: +49 531 592-31 22, e-mail: rainer.stosch@ptb.de

identical to the analyte but isotopically labelled (isotopomer) is added to the sample. Due to the mass difference, the optical selectivity of the Raman effect provides separate signals for the two substances so that the quantity of the unknown can be determined from the quantity of the known. The evaluation of the spectra is therefore reduced to the determination of intensity ratios, which is of special interest for metrological purposes. Potential disturbing effects such as material losses or matrix effects, which equally affect both isotopomers of the analyte, have no influence on the result.

This approach of a primary ratio method is well known from mass spectrometry and was developed and validated here by means of a practically relevant example: the determination of the creatinine concentration in blood serum, a value that provides information about the functional efficiency of the kidneys. Compared to the optical measurement methods used up to now, results could be obtained whose detection limit has been improved by as much as three orders of magnitude. In this way, the measurement accuracy is increased to the extent that even the highest metrological requirements can be met.



Highest temperatures precisely fixed

PTB *news* 06.2
English edition
August 2006
ISSN 1611-1623X

Published by
Physikalisch-Technische
Bundesanstalt (PTB)
Braunschweig and Berlin
Germany

Chief Editor *Jens Simon*
PTB, Bundesallee 100
D-38116 Braunschweig
phone: (+49 531) 592-30 06
fax: (+49 531) 592-30 08
e-mail: ptbnews@ptb.de
Website: http://www.ptb.de/

Further information can be obtained from
K. Anhalt,
phone: +49 30 34 81-74 27,
E-Mail: klaus.anhalt@ptb.de

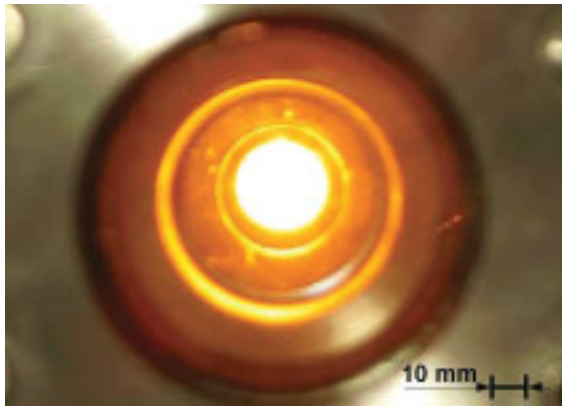
With the aid of radiation thermometry based on Planck's radiation law, PTB could determine the melting temperatures of novel eutectic metal-carbon alloys (M-C alloys) up to nearly 3000 °C for the first time with low measurement uncertainties. To improve industrial high-temperature measurements, these M-C alloys shall in future be used to determine high-temperature fixed points.

The measurement of high and highest temperatures is decisive for the efficient use of resources e.g. in power engineering or aerospace industry. A service temperature that is too high or too low by 20 °C reduces, for example, the service life of a turbine operated at 1500 °C by 50 %, and safety can also depend on precise high-temperature measurements, e.g. when space shuttles re-enter the Earth's atmosphere.

The currently valid international temperature scale of 1990 (ITS-90) was defined with the aid of a series of fixed points with fixed temperatures. The highest fixed-point temperature of 1085 °C is the setting temperature of copper; beyond this temperature, the ITS-90 depends on extrapolation with increasing measurement uncertainty. Up to now, the precision of high-temperature measurements has therefore been limited by the lack of even higher, reproducible melting and setting temperatures.

The Japanese State Institute's proposition in 1999 to use M-C alloys for such high-temperature fixed points, since the carbon alloys of different metals have melting points from 1150 °C to over 3000 °C, gave a prospect of improvement. To prepare the transfer of these materials to industrial application, PTB, in cooperation with the Japanese and the Russian State Institutes, investigated them in detail within the scope of an EU-project. For the first time, PTB succeeded in precisely determining the melting temperatures of M-C alloys for temperatures up to 2880 °C. For Re-C (melting temperature 2475 °C) for example, an expanded measurement uncertainty of less than 1 °C could be achieved with a reproducibility between different fixed-point cells of less than 0.2 °C.

Currently, PTB is taking part in a global project for the improvement of the International Temperature Scale by implementation of the new high-temperature fixed points.



View into a Re-C cell during melting at 2475 °C. The cell was developed within the scope of the HIMERT EU project.