PTB news
Metrology
Technology
Services
Cooperation
05.3

Ultra-fast magnetic memories

In the future, a new bit-triggering procedure developed at PTB will enable non-volatile magnetic memory components (i.e.: magnetic random access memory: MRAM) access times below 500 ps. This means that, for the first time, a non-volatile memory chip would be as fast as the fastest volatile memory components.

Fast memory chips commonly used today such as DRAMs and SRAMs have one decisive disadvantage: in case of power supply interruption, they lose their stored information. MRAMs promise to solve this problem. The digital information in a MRAM is stored as a magnetization direction in magnetic cells and not an electrical charge status. All large chip producers are participating in the development of this novel memory chip. Launching of the chip is imminent.

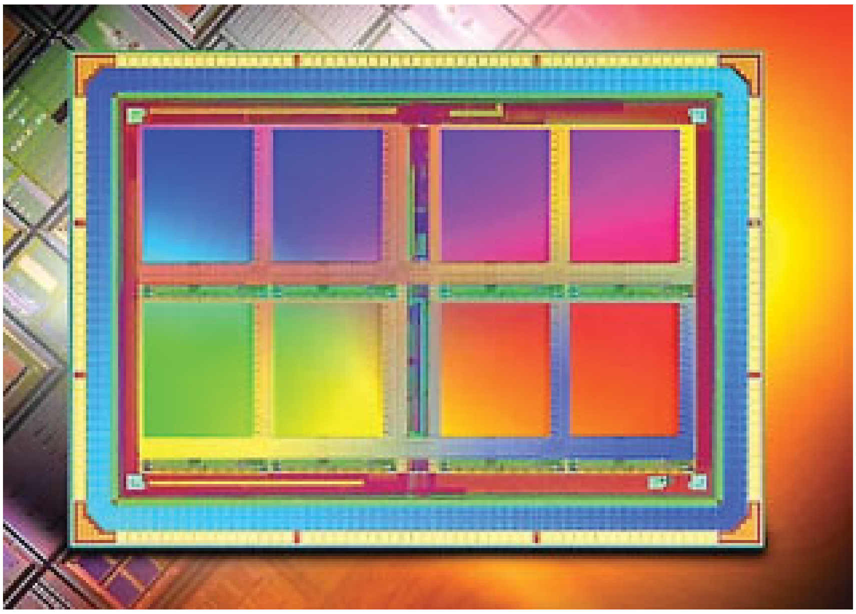
At present, MRAM programming of a magnetic bit takes, however, about 10 ns. Faster operation has hitherto been impeded by a physical property of the magnetic memory cells: when writing a specific cell in the MRAM chip, magnetic excitations also occur in a great number of other cells. These excitations are only weakly damped and need up to 10 ns to die out. During this time, no other cell can be programmed so that the maximum clock rate of the MRAM is limited to approx. 100 MHz.

With the aid of a bit-triggering procedure developed at PTB and for which a patent has been applied, this limitation of the MRAM clock rate can now be avoided. In the case of the so-called "ballistic bit triggering", magnetic excitations in all cells of the MRAM are avoided almost completely by skilful selection of the magnetic pulses used for programming.

The pulses are selected in such a way that magnetization of the cell to be switched performs half (180°) a precision rotation, while a full (360°) precision rotation occurs in the cell, whose memory state is to remain unchanged. In both cases, magnetization is in equilibrium after switch-off of the pulses and additional magnetic excitations no longer occur.

This optimal bit triggering can be performed with very short switching pulses (duration below than 500 ps), which leads to maximum MRAM clock rates of more than 2 GHz. Construction of a non-volatile memory component, the clock rate of which can compete with the fastest volatile memory components – the SRAM – is possible for the first time. Parallel programming of several bits at the same time could increase the effective MRAM write rate per bit even by another order of magnitude.

Further information can be obtained from H. W. Schumacher, phone: (+49 531) 592-24 14, email: hans.w.schumacher@ptb.de



4MBit MRAM Chip of the firm of *freescale* (formerly *Motorola)*

The micro-ion beam is speeding up

A new device at the PTB's micro-ion beam facility allows irradiating several hundred cells individually per second. The procedure is thus about ten times faster than previously. It can now be efficiently used to investigate radiation damage mechanisms in individual cells. Understanding the damage mechanisms is important for dosimetry in the low-dose range.

The radiation experiments on living cells are performed in cooperation with institutes in the field of radiobiological research. An important subject of the investigations is the so-called bystander effect, which refers to the occurrence of a measurable effect on a non-radiated cell when a neighbouring cell was irradiated.

To make irradiations faster and more precise an electrostatic deflection unit has been added to PTB's micro-ion beam facility. The unit can deflect the beam within a millisecond with micrometer accuracy. Time-consuming mechanical positioning of each individual cell can thus be omitted. Now it is

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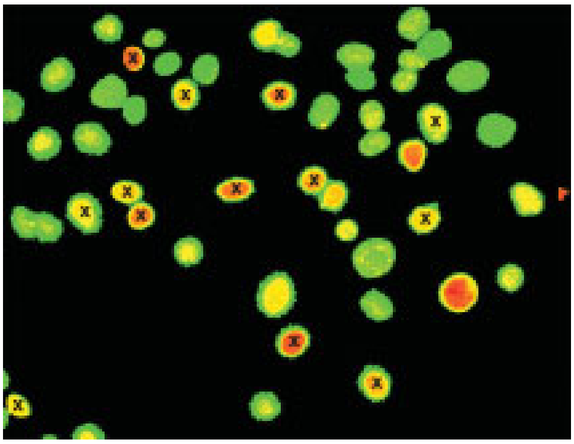
possible to irradiate several hundred cells per second individually. Including all preparative steps, the experimental throughput could be increased to up to 50 000 cells per hour, i.e. it could be increased tenfold. The position accuracy could also be slightly improved: Deflection of the beam now only shows an uncertainty of approx. 0.5 µm, half the amount hitherto achieved with mechanical positioning.

The second important contribution to an increase in efficiency was the extension of the cell recognition software. With the aid of a newly developed module for the quantification of protein colouring one can now investigate which processes take place in a cell at a given moment in time. There are, for example, proteins which are required to repair DNA inherent in the cell or which indicate the beginning of the programmed cell death (apoptosis). To investigate the bystander effect it is important that the radiated and non-radiated cells are found on the same carrier (by using the position data stored and reference positions). Then, activation of the protein p53, – a fast indicator of a stress condition of the cell –, is measured with a CCD camera. Correlation with the radiation information then furnishes information about the communication path of the bystander effect.



Measured activation of protein p53 in cell nuclei as a measure of the radiation damage: red means high, green: low activation. The cells marked with an × had been irradiated.

Further information can be obtained from K.-D. Greif, phone: (+49 531) 592-64 81, email: klaus-dieter.greif@ptb.de

Avogadro Project: First isotope-pure silicon single-crystal

Within the scope of the international Avogadro Project, the objective of which is to re-determine the Avogadro constant, a perfect isotopically and chemically pure silicon single-crystal has been successfully manufactured for the first time. A sample crystal of over 400 g in mass and more than 99.99% isotopic purity was delivered to PTB for test measurements.

One goal of the Avogadro Project, is to determine the quantity of the Avogadro constant with unprecedented accuracy. This would also give rise to a definition of the kilogramme, which is still embodied by a prototype, referenced to a fundamental constant. Measurements performed on silicon spheres with a natural isotopic composition did not allow relative uncertainties of less than $3 \cdot 10^{-7}$ to be achieved for the Avogadro constant. Therefore, it was decided to repeat the measurements with isotopically pure silicon. For this purpose, PTB coordinated a cooperation agreement between eight national metrology institutes, international research laboratories and Russian research institutions and industrial firms. The first result of this cooperation is the single-crystal now available. The crystal was a joint-production of the Central Office for Centrifuge Development of the Russian Nuclear Ministry in St. Petersburg (production and enrichment of SiF_4 gas), the Institute for Ultrapure Materials in Nishni-Novgorod (converting SiF_4 gas into SiH_4 gas, chemical purification and separation of a poly-crystal) and the Institute for Crystal Growth in Berlin (growing the Si single-crystal by means of zone purification procedures). The chemical purity required for further use of the material in producing the sphere was achieved after several float zone melting processes. At PTB, the impurity concentrations were determined by infrared spectrometry: carbon $3 \cdot 10^{15}$ cm^{-3}, oxygen $4 \cdot 10^{15}$ cm^{-3} and boron $3 \cdot 10^{13}$ cm^{-3}. The content of more than 99.99% ^{28}Si in the crystal, determined at the Institute for Reference Materials and Measurements of the EU in Geel, was maintained through out the entire production process. This is an important prerequisite for successful measurements on a ^{28}Si sphere. The material required, a 5 kg crystal, will be delivered within schedule in 2006.

Further information can be obtained from P. Becker, phone: (+49 531) 592-43 00, email: peter.becker@ptb.de

Towards the global natural gas cubic meter

After the cubic meter for natural gas under high pressures was unified by the national German, French and Dutch metrology institutes (PTB, LNE and NMi-VSL) last year, international Key Comparisons for high-pressure gas have been completed in April 2005. Participants, for the time being, were limited to these European institutes, and a Key Comparison Reference Value (KCRV) has been determined.

Public gas economy is a gigantic market. In Germany alone, approximately 100 billion cubic meters of natural gas flow each year through the pipeline systems to the end customer. As this corresponds to a monetary value of approximately 20 billion euros, customers and suppliers are interested in precise measurements. Under optimal conditions, the best test facilities for flowrate measurements on high-pressure natural gas pipes, however, merely achieve a measurement uncertainty in the order of 0.15%. However, in the past additional contributions to the measurement uncertainty could occur as well because Germany, the Netherlands and France had realized completely different concepts for natural gas measurements. Thus unfavourable effects on gas trade were possible.

By May 4, 2004 a uniform cubic meter for natural gas under high pressures, referred to as the "harmonized European natural gas cubic meter", had been realized by the German, Dutch and French metrology institutes (PTB, LNE and NMi-VSL). In this procedure – regulated by contract –, a weighted mean value was created out of the three independent realizations of the partners involved. No other metrologically independent realizations has been established in Europe by other countries. A stable and reliable European standard has thus been created which is affected by a lower overall uncertainty than the individual realizations in the participating institutions. It represents a benefit for fair trade in the gas supply economy.

To extend the recognition of calibration certificates outside Europe, key comparisons are organized within the scope of the international activities of CIPM/BIPM in all important metrological fields. In the natural gas sector, operators of governmental and private high-pressure test facilities from all over the world were invited to participate. As calibration test facilities for high-pressure natural gas operated by metrology institutes are evidently not available outside Europe, only the European metrology institutes PTB, LNE and NMi-VSL participated in the international comparison measurement under supervision of CIPM/BIPM. The KCRV determined in the comparison is identical with the natural gas cubic meter determined in Europe. On this basis PTB supports the establishment of corresponding national standards in different countries including non-European ones to complete global harmonization.

The natural gas cubic meter was uniformly realized on the European test facilities pigsar, Bergum and LADG.

Further information can be obtained from D. Dopheide, phone: (+49 531) 592-14 00, email: dietrich.dopheide@ptb.de

Against the trend: NMR measurements in low fields

Today ever stronger static magnetic fields are used to increase the spectral resolution of nuclear magnetic resonance measurements (NMR measurements). It is, however, also possible to follow an opposite approach and to record NMR spectra in very low magnetic fields with superconducting quantum interferometers (SQUIDs) with excellent spectral resolution. At PTB, a low-field NMR spectrometer has been developed which achieves a resolution of far below 1 Hz in the new magnetically shielded BMSR-2 room. This opens up the possibility of performing improved and novel NMR measurements.

At first it seems surprising that at very low fields of a few micro- or even nanotesla flux density, a spectral resolution can be achieved which by far exceeds that of conventional high-field spectrometers. The reason is quite simple: The resonance lines are always broadened by field inhomogeneities which scale with the field strength. This is why, for example, recording the natural line widths of benzene, chloroform or distilled water around 0.1 Hz becomes possible for magnetic flux densities between 40 nT and 4 μT. As chemical shift displacement also disappears in the low-field range, the spectra of more complex molecules are simplified. In cooperation with the universities of Magdeburg

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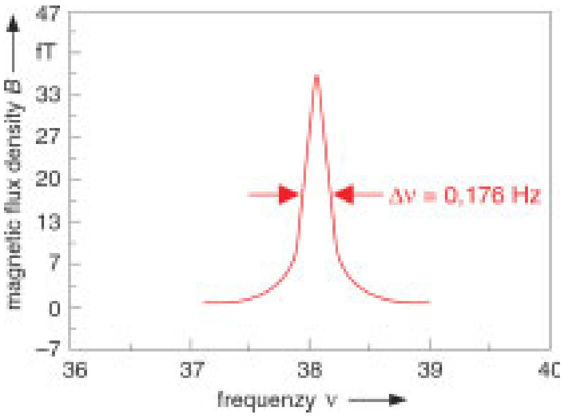
and Jena, broad-band "low field" NMR spectra were measured and numerically simulated for a series of molecular systems which contain different nuclear moments. It turned out that the resolution of so-called hetero-nuclear J couplings was limited only by the natural widths of the resonance lines. The higher resolving capacity of the new technique thus allows a better analysis of reactions in which different nuclei are involved.

On the basis of these results it can be expected that in the low-field range, also MR imaging in the field of medicine will become possible. The magnetic fields produced naturally in the body and generated by bioelectric currents in the heart or in the brain are of the same order of magnitude and they can be recorded simultaneously by SQUIDs. This opens up the interesting new possibility of investigating the function and anatomy of organs with one single measurement.



Measured NMR spectrum of distilled water, detection field: 900 nT. Contrary to high detection fields, the natural line width of about 0.15 Hz is broadened only insignificantly by the measuring device.

Further information can be obtained from M. Burghoff, phone: (+49 30) 34 81-72 38, email: martin.burghoff@ptb.de

Radiation exposure mapped at flight altitudes

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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/
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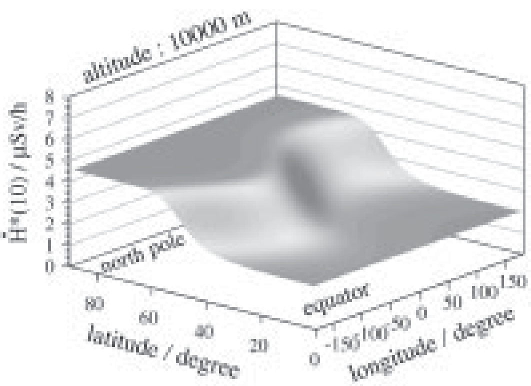
In aviation, flying personnel is especially exposed to cosmic radiation. Permanent PTB measurements on board an airliner have now mapped this radiation for the northern hemisphere so that reliable forecasts can be made for the actual radiation exposure at flight altitudes.

For several years, PTB has performed measurements at flight altitudes to investigate the global distribution of the ambient equivalent dose rate created by cosmic radiation at cruising altitudes. Between December 2003 and September 2004, a first long-term measurement was performed. The measuring system, which merely has the size of a flight case, was installed on board a Lufthansa Airbus A340. In more than 250 flights over the northern hemisphere, a great number of measurement data was collected. From these measurement data, easily manageable mathematical functions were obtained which describe the dependence of the ambient equivalent dose rate on latitude and altitude. This allows a calculation to be performed at least at cruising altitudes between 9 km and 12 km in the northern hemisphere. A comparison with measurements from the years 1997 to 1999 – in which time, however, only 39 individual measurement flights were carried out – allowed determining the functional relationship between a neutron measurement station on the ground – as a measure of solar activity,– and the radiation exposure at flight altitudes. Solar activity was found to influence the dose rate by up to ±30 %. The results of these measurements are contained in the "FDOScalc" *(Flight Dose Calculator)* program and are available to the public via the web pages of PTB (http://www.ptb.de/flugdosisrechner.html). PTB itself will use FDOScalc to check other dose determination programs which calculate the radiation exposure at flight altitudes and which must have the Federal Office of Civil Aviation (Luftfahrtbundesamt) approval.

Further information can be obtained from F. Wissmann, phone: (+49 531) 592-63 30, email: frank.wissmann@ptb.de



Distribution of the ambient equivalent dose rate at an altitude of 10 km in the northern hemisphere from equator to North Pole. The distribution takes all data into account which have been obtained in the course of the permanent measurement (9 months) on board a Lufthansa Airbus.