## SCIENCE NEWS


### 3-D X-ray Imaging Makes the Finest Details of a Computer Chip Visible

Researchers of the Paul Scherrer Institute (PSI) have made detailed 3-D images of a commercially available computer chip. This marks the first time a non-destructive method has visualised the paths of a chip's internal wiring (just 45 nanometres— 45 millionths of a millimetre — wide) and its 34-nanometre-high transistors clearly without distortions or deformations. It is a major challenge for manufacturers to determine if, in the end, the structure of their chips conforms to the specifications. Thus these results represent one important application of an X-ray tomography method that the PSI researchers have been developing for several years. In their experiment, the researchers examined a small piece that they had cut out of the chip beforehand. This sample remained undamaged throughout the measurement. The goal now is to extend the method in such a way that it can be used to examine complete chips. The researchers conducted the experiments at the Swiss Light Source (SLS) of the Paul Scherrer Institute. They report their results in the latest edition of the journal *Nature*.

The electrical wiring in many of the electronic chips in our computers and mobile phones are just 45 nanometres wide, the transistors 34 nanometres high. While it is standard practice today to produce structures this delicate, it remains a challenge to measure the exact structure of a finished chip in detail in order to check, for example, if it is built according to the specifications. Nowadays, for such examinations, manufacturers mainly use a method in which layer after layer of the chip is removed and then, after each step, the surface is examined with an electron microscope; this is known as FIB/SEM — focused ion beam or scanning electron microscope imaging.

Now researchers of the Paul Scherrer Institute have used X-rays to achieve non-destructive 3-D imaging of a chip, so that the paths of the conducting lines and the positions of the individual transistors and other circuit elements became clearly visible. "The image resolution we were able to produce is comparable to the conventional FIB/SEM examination method," explains Mirko Holler, leader of the project. "But we were able to avoid two significant disadvantages: Firstly, the sample remained undamaged, and we have complete information about the three-dimensional structure. Secondly, we avoided distortions of the images that arise in FIB/SEM if the surface of the individual slice is not exactly planar."

### Positioned with Nanometre Precision

For their study, the researchers used a special tomographic method (ptychotomography) that they have developed and enhanced over the course of recent years, and which today offers the worldwide best resolution of 15 nanometres (15 millionths of a millimetre) for examination of a comparably large volume. In the experiment the object to be studied is X-rayed at precisely determined places with light from the Swiss Light Source (SLS) of the Paul Scherrer Institute — for each illuminated spot a detector then measures the X-ray light pattern after its passage through the sample. The sample is then rotated in small steps and then X-rayed again step-wise after each turn. From the whole set of data obtained, the three-dimensional structure of the sample can be determined. "With these measurements, the position of the sample must be known to a precision of just a few nanometres — that was one of the particular challenges in setting up our experimental station," Holler says.

In their experiment the researchers examined small pieces of two chips — a detector chip developed at PSI and a commercially available computer chip. Each piece was about 10 micrometres (that is, 10 thousandths of a millimetre) in size. While the examination of an entire chip with the present measurement setup is not possible, the method's advantages are brought to bear even in this form, so that the first prospective users have already expressed an interest in conducting measurements at PSI.

### The Goal: to Examine Entire Microchips

"We are currently starting to extend the method in such a way that it can be used to examine entire microchips within an acceptable measurement time. Then it will also be possible to study the same area of a chip multiple times, for example to observe how it changes under external influences," explains Gabriel Aeppli, head of the Synchrotron Radiation and Nanotechnology Division at the PSI.

## A New Model for Capillary Rise in Nano-channels Offers Insights into Improved Hydraulic Fracturing (Fracking)

In the last decades, hydraulic fracturing or 'fracking,' a method of oil and gas extraction, has revolutionised the global energy industry. It involves fracturing rock with a pressurised liquid or 'fracking fluid' (water containing sand suspended with the aid of thickening agents) to draw out small oil and gas deposits trapped in stone formations.

After the water molecules of the fracking fluid are injected into these formations, they rise up the stone walls of the small channels where they have flowed. They can then undergo 'imbibition,' a type of diffusion that involves them being absorbed via nano-pores into the neighbouring pockets where the oil and gas reside. As the water molecules are absorbed, the oil and gas molecules are displaced and can then be pumped to the surface. This activity is driven by the capillary force between the water and oil, which results from the tension generated at the interface or point where the two fluids meet.

Scientists have typically calculated the expected level of capillary rise in these conditions with the Lucas-Washburn equation, a mathematical model whose earliest parameters were first devised nearly a century ago. The challenge, however, is that that the equation has not been completely accurate in predicting the actual rise observed in nano-capillary laboratory experiments.

"The height of the capillary rise that was observed in these experiments was lower than what the Lucas-Washburn model would have predicted," explained Anqi Shen, a doctoral student at China's Northeast Petroleum University who works closely with Yikun Liu, a professor at the university. "Understanding what was causing this deviation became an important point of focus for my colleagues and me."

The researchers describe their findings this week in the journal *Applied Physics Letters,* from AIP Publishing.

"Many explanations have been offered for the lower-than-expected capillary rise. One area of discussion has focused on the viscosity of the fluid. Another has been the sticky layers of oil that form on the walls of the capillaries and narrow their diameter, which is an issue that we have also explored," Shen said, whose work is also funded by the Major Projects Program for the National Science and Technology of China.

"We looked at many factors and found that the surface roughness of the capillaries was the main reason for the lower-than-expected result. Specifically, we realised that the model could better determine the actual level of capillary rise if we adjusted the parameters to account for the frictional drag that is caused by the inherent roughness of the surface of the capillary walls. When we saw how this made the model more accurate, we knew that we could not ignore it," Shen said.

Moreover, the miniscule size of the capillaries means that even small increases in surface roughness can make a significant impact on calculations.

"Factors that might be ignored in normal conditions can have significant effects on a micro or nano level. For instance, a relative roughness of 5 per cent, in a tube with a radius of 100 cm where the obstacle height is 5 cm hardly affects the fluid flow in the tube. However, with a tube radius of 100 nm and obstacle height of 5 nm, it could significantly affect the fluid flow in the tube," Shen said.

Currently, there are only a few labs carrying out nano-capillary rise experiments. As a result, Shen and her colleagues could only work with the results from one laboratory in the Netherlands. Going forward, they intend to verify their mathematical formula by examining its effectiveness at simulating the results of other experiments.

Although Shen's research focuses on oil and gas development, she and her colleagues hope that their work can be of use to scientists working in other fields.

"Capillary rise is a basic, physical phenomenon that occurs in soil, paper, and other biologically relevant realms," Shen said. "Understanding how it is potentially affected at the nano-capillary level by frictional drag could shed light in a variety of scientific disciplines."

## A New Theory to Describe Widely Used Material

LiU researcher Klas Tybrandt has put forward a theoretical model that explains the coupling between ions and electrons in the widely used conducting polymer PEDOT:PSS. The model has profound implications for applications in printed electronics, energy storage in paper, and bioelectronics.

One of the most commonly used materials in organic electronics is the conducting polymer PEDOT:PSS, and tens of thousands of scientific articles have been published referring to the material and its properties. One of the major advantages of PEDOT:PSS is that it conducts both ions and electrons, but a model that explains how this works has, until now, not been available. We know that the material has several useful properties, but we don't know why.

Klas Tybrandt, principal investigator in the Soft Electronics group at the Laboratory of Organic Electronics, Campus Norrköping, has developed a theoretical model for the interaction between ions and electrons that explains how ion transport and electron transport are related. The model has been published in the journal *Science Advances*.

"Classical electrochemical models have mainly been used in the past for this type of system, and this has led to a certain degree of confusion, since the models do not include the properties of semiconductors. We have used a purely physical description that clarifies the concepts," says Klas Tybrandt.

The material is a mixture of a semiconducting polymer and a polymer that conducts ions. The two phases are mixed down to the nanometer-scale, and even a thin film contains a huge number of interfaces. At the contact surface between the electronic and the ionic phases, what is known as an 'electrical double layer' forms, which means that a charge separation builds up here between ions and electrons.

"We have combined semiconductor physics with a theory for electrolytes and electrical double layers, and we have been able to describe the properties of the material on a theoretical basis. We have also experimental results showing that the model agrees with laboratory measurements," says Klas Tybrandt.

PEDOT:PSS is one of several polymeric materials that act in the same way. Increased understanding of the material and its unique properties is a major advance for researchers in several areas of organic electronics.

One such area is printed electronics, where it is now possible to calculate and optimise the performance of electrochromic displays and transistors.

Another area that benefits from the new model is bioelectronics. Here, materials that conduct both ions and electrons are particularly interesting, since they can couple the ion conducting systems of the body with the electronic circuits in, for example, sensors.

"We can optimise the applications in a completely new way, now that we understand how these materials work," says Klas Tybrandt.

A third area is the storage of energy in paper, a field in which LiU researchers are world-leaders.

"Understanding the complexity of these polymers allows us to develop and optimise the technology. This will be one of the areas for the newly opened Wallenberg Wood Science Center," says Klas Tybrandt.

Main funding for the project has been provided by the Swedish Research Council and the Swedish government's Strategic Research Area Initiative into Advanced Functional Materials at Linköping University.

The article 'Chemical potential-electric double layer coupling in conjugated polymer-polyelectrolyte blends', written by Klas Tybrandt, Igor V Zozoulenko and Magnus Berggren, Laboratory of Organic Electronics, Linköping University, has been published in *Science Advances*.

## Big Data Approach to Predict Protein Structure

Nothing works without proteins in the body, they are the molecular all-rounders in our cells. If they do not work properly, severe diseases, such as Alzheimer's, may result. To develop methods to repair malfunctioning proteins, their structure has to be known. Using a big data approach, researchers of Karlsruhe Institute of Technology (KIT) have now developed a method to predict protein structures.

In the *Proceedings of the National Academy of Sciences (PNAS)* of the United States of America the researchers report that they succeeded in predicting even most complicated protein structures by statistical analyses irrespective of the experiment. Experimental determination of protein structures is quite cumbersome, success is not guaranteed. Proteins are the basis of life. As structural proteins, they are involved in the growth of tissue, such as nails or hairs. Other proteins work as muscles, control metabolism and immune response, or transport oxygen in the red blood cells.

The basic structure of proteins with certain functions is similar in different organisms. "No matter whether human being, mouse, whale or bacterium, nature does not constantly invent proteins for various living organisms anew, but varies them by evolutionary mutation and selection," Alexander Schug of the Steinbuch Centre for Computing (SCC) says. Such mutations can be identified easily when reading out the genetic information making up the proteins. If mutations occur in pairs, the protein sections involved mostly are located close to each other. With the help of a computer, the data of many spatially adjacent sections can be composed to an exact prediction of the three-dimensional structure similar to a big puzzle. "To understand the function of a protein in detail and to influence it, if possible, the place of every individual atom has to be known," Schug says.

For his work, the physicist uses an interdisciplinary approach based on methods and resources of computer science and biochemistry. Using supercomputers, he searched the freely available genetic information of thousands of organisms, ranging from bacteria to the human being, for correlated mutations. "By combining latest technology and a true treasure of datasets, we studied nearly two thousand different proteins. This is a completely new dimension compared to previous studies," Schug adds. He emphasises that this shows the high performance of the method that promises to be of high potential for applications ranging from molecular biology to medicine. Although present work is fundamental research according to Schug, the results may well be incorporated in new treatment methods of diseases in the future.

## Math Learned Best When Children Move

Children improve at math when instruction engages their own bodies. This is one of the findings from a recent study coming from the University of Copenhagen's Department of Nutrition, Exercise and Sports. The results also document that children require individualised learning strategies.

The project has investigated whether different types of mathematics learning strategies change the way children solve math problems.

Well-being and learning among school age children has a significant impact on how children fare later on in life. Therefore, frameworks for elementary school teaching and learning must be optimised. The 2014 Danish School Reform emphasised physical activity during the primary and lower secondary education years — as apart of academic instruction as well. Researchers from the Department of Nutrition, Exercise and Sports have investigated the effect of different types of primary school mathematics instruction.

### It Helps to Use the Whole Body

Results from the study underscore that many children improve at math when their bodies are engaged during instruction, and that math instruction should be individualised.

"The children learn more if they move and use the whole body to learn," according to head researcher and Associate Professor Jacob Wienecke of the University of Copenhagen's Department of Nutrition, Exercise and Sports. "Compared to previous studies which demonstrated that intense physical activity could improve learning outcomes, we have been able to show that lower intensity activities are just as effective, or even more effective, as long as movement is integrated into the topic at hand."

After just six weeks of the study, all of the children improved their scores in a standardised fifty question national test. Children whose instruction included whole body activity performed best. Their performance improved by 7.6 per cent, with nearly four more correct responses than the baseline, and twice as much improvement as the sedentary fine motor skills group.

### Differentiated Instruction is Crucial

When children were grouped according to pre study math performance, the results demonstrated that children with average and above average performance benefited most from using the entire body in learning. Children who weren't very good at math prior to the study received no particular benefit from the alternative instructional forms.

"We need to keep this in mind when developing new forms of instruction," according to Associate Professor Wienecke, who continues: "The new school reform focuses on, among other things, the incorporation of physical activity during the school day, with the aim of improving the motivation, well-being and learning of ALL children. However, individual understanding must be taken into account. Otherwise, we risk an unfortunate combined outcome in which those who are already proficient advance, and those who have not yet mastered concepts cannot keep up."

The researchers are now investigating which areas of the brain are involved in these various learning strategies. At the same time, researchers will be testing the School Reform's positive effects on other academic skills, such as reading.

Results of the study have just been released in the article, Motor-enriched Learning Activities Can Improve Mathematical Performance in Preadolescent Children, published in the internationally renown scientific journal, *Frontiers in Human Neuroscience.*

### About the Study

The University of Copenhagen's Department of Nutrition, Exercise and Sports studied the effect of various instructional types related to mathematics instruction for Danish primary school students. 165 Danish first grade students, divided among three schools in the Copenhagen area participated in a six-week study.

The children were divided into three groups:

- One group used the whole body during mathematics education. Teaching took place on the classroom floor, with tables and chairs set to the side. Students were included in problem solving by, for example, making a triangle or shaping numerals with their bodies, or using one another when being asked to add or subtract.
- Another group of students was sedentary and worked on math using fine motor skills. These children worked independently or in small groups using LEGO-bricks in a classroom setting. For example, they used bricks for arithmetic or to build models for solving geometry tasks.
- A control group engaged in regular mathematics instruction, using pencils, paper, rulers and the like.

## Does the Universe Have a Rest Frame?

Physics is sometimes closer to philosophy when it comes to understanding the universe. Donald Chang from Hong Kong University of Science and Technology, China, attempts to elucidate whether the universe has a resting frame. The results have recently been published in *EPJ Plus.*

To answer this tricky question, he has developed an experiment to precisely evaluate particle mass. This is designed to test the special theory of relativity that assumes the absence of a rest frame, otherwise it would be possible to determine which inertial frame is stationary and which frame is moving. This assumption, however, appears to diverge from the standard model of cosmology, which assumes that what we see as a vacuum is not an empty space. The assumption is that the energy of our universe comes from the quantum fluctuation in the vacuum.

In a famous experiment conducted by Michelson and Morley in the late 19th century, the propagation of light was proved to be independent of the movement of the laboratory system. Einstein in his Special Theory of Relativity, inferred that the physical laws governing the propagation of light are equivalent in all inertial frames — this was later extended to all physics laws not just optics.

In this study, the author set out to precisely measure the masses of two charged particles moving in opposite directions. The conventional thinking assumes that the inertial frame applies equally to both particles. If that is the case, no detectable mass difference between these two particles is likely to arise. However, if the contrary is true, and there is a rest frame in the universe, the author expects to see mass difference that is dependent on the orientation of the laboratory frame. This proposed experiment partially inspired by the Michelson and Morley experiments can be conducted using existing experimental techniques. For simplicity, an electron can be used as the charged particle in the experiment.

## How Cheetahs Stay Fit and Healthy

Cheetahs are categorised as vulnerable species, partly because they have been considered to be prone to diseases due to their supposed weak immune system. However, they are hardly ever sick in the wild. A research team from the German Leibniz Institute for Zoo and Wildlife Research (IZW) recently discovered that cheetahs have developed a very efficient innate 'first line of defense' immunity to compensate potential deficiencies in other components of their immune system. The scientists have published their results in the open access journal *Scientific Reports* of the Nature Publishing Group.

Cheetahs have a relatively low genetic variability which means that, within a population, the individuals have a similar genetic makeup. This is also true for the major histocompatibility complex (MHC), a genome region that regulates the so-called 'adaptive' immune system and is typically highly variable in animal species. The adaptive immune system provides a rapid and specific defense against pathogens, if they have been encountered previously. A low MHC variability should, therefore, result in a weak adaptive immune system and, thus, a high vulnerability to diseases. This is often the case in species with low MHC variability, but there are some exceptions, the cheetah indeed being one of them. "During our long-term study that began in 2002, we investigated more than 300 free-ranging cheetahs that live on farmland in Namibia. We did not encounter any cheetah with symptoms of acute infections, nor did we detect lesions in the examined dead animals," explains Bettina Wachter, head of the cheetah research project.

How can cheetahs cope so well with pathogens despite their supposedly weak adaptive immunity? The immune system is divided into three components: (1) the constitutive innate immune system, which provides a rapid first line of defense against intruders, (2) the induced innate immune system such as the local and systemic inflammatory response, which enhances recovery and decreases pathogen growth, and (3) the adaptive immune system.

"We decided to investigate all three components simultaneously, an approach that is rarely done although it is very promising. For every animal, a well-functioning immune system is associated with certain energetic costs. However, this does not imply that all immune components are equally strongly developed. If a species is not vulnerable to diseases, a good immune response must have evolved by strengthening other parts of the immune system," says Gábor Czirják, wildlife immunologist at the Leibniz-IZW.

To compare the results with another species, the scientists included leopards in the study. "Leopards live in the same habitat as cheetahs in Namibia, but they have a high variability in their MHC. Thus, leopards should have a strong adaptive immune system and might not invest that much energy in the other parts of the immune system," explains Wachter.

"We first needed to adapt six immunological tests from the toolbox of the wildlife immunology for the cheetah and leopard," explains Sonja Heinrich, first author of the study. "We conducted these tests at the laboratory of the Leibniz IZW, thus needed to transport the samples we collected in Namibia all the way to Germany, keeping the cooling chain uninterrupted from the captured animal in the field to the Leibniz IZW." The immunological tests confirmed that leopards have a stronger adaptive immune system than cheetahs, consistent with the differences in the MHC variability of both species. As expected, cheetahs had a stronger innate 'first line of defense' immune system than leopards, thereby probably compensating their weak adaptive immune system.

The induced innate immune system reacts to pathogen intruders as well as to temporary stress. Therefore, the scientists also determined the concentration of the hormone cortisol, which activates catabolic processes and is increasingly released during stress. Although both species were exposed to the same capture and handling procedures leopards had significantly higher cortisol concentration in their blood than cheetahs, indicating that leopards reacted stronger to the examination methods. Thus, short-term stress might have stimulated the induced innate immune system, making it difficult to assess whether this immune part also helps to compensate the weak adaptive immune system of cheetahs, if the stress effect is not considered.

This is the first study in mammals demonstrating that different species spend varying efforts in the development of the different immune components. Cheetahs have apparently developed a way to successfully fight against pathogens despite their low genetic variability in their MHC. However, the future of this vulnerable species is highly uncertain because most of their habitat occurs in unprotected areas and they frequently come into conflicts with humans. Only if these conflicts can be mitigated, the cheetahs have a good chance to persist in the wild in the future.

## Research Leads to a Golden Discovery for Wearable Technology

Some day, your smartphone might completely conform to your wrist, and when it does, it might be covered in pure gold, thanks to researchers at Missouri University of Science and Technology.

Writing in the March 17 issue of the journal *Science*, the Missouri S&T researchers say they have developed a way to 'grow' thin layers of gold on single crystal wafers of silicon, remove the gold foils, and use them as substrates on which to grow other electronic materials.

The research team's discovery could revolutionise wearable or 'flexible' technology research, greatly improving the versatility of such electronics in the future.

According to lead researcher Dr Jay A. Switzer, the majority of research into wearable technology has been done using polymer substrates, or substrates made up of multiple crystals. "And then they put some typically organic semiconductor on there that ends up being flexible, but you lose the order that (silicon) has," says Switzer, Donald L. Castleman/FCR Endowed Professor of Discovery in Chemistry at S&T.

Because the polymer substrates are made up of multiple crystals, they have what are called grain boundaries, says Switzer. These grain boundaries can greatly limit the performance of an electronic device.

"Say you're making a solar cell or an LED," he says, "In a semiconductor, you have electrons and you have holes, which are the opposite of electrons. They can combine at grain boundaries and give off heat. And then you end up losing the light that you get out of an LED, or the current or voltage that you might get out of a solar cell."

"Most electronics on the market are made of silicon because it's relatively cheap, but also highly ordered," Switzer says.

"99.99 per cent of electronics are made out of silicon, and there's a reason – it works great," he says. "It's a single crystal, and the atoms are perfectly aligned. But, when you have a single crystal like that, typically, it's not flexible."

By starting with single crystal silicon and growing gold foils on it, Switzer is able to keep the high order of silicon on the foil. But because the foil is gold, it's also highly durable and flexible.

"We bent it 4,000 times, and basically the resistance didn't change," he says.

The gold foils are also essentially transparent because they are so thin. According to Switzer, his team has peeled foils as thin as seven nanometers.

Switzer says the challenge his research team faced was not in growing gold on the single crystal silicon, but getting it to peel off as such a thin layer of foil. Gold typically bonds very well to silicon.

"So we came up with this trick where we could photo-electrochemically oxidize the silicon," Switzer says. "And the gold just slides off."

Photoelectrochemical oxidation is the process by which light enables a semiconductor material, in this case silicon, to promote a catalytic oxidation reaction.

Switzer says thousands of gold foils—or foils of any number of other metals—can be made from a single crystal wafer of silicon.

The research team's discovery can be considered a 'happy accident.' Switzer says they were looking for a cheap way to make single crystals when they discovered this process.

"This is something that I think a lot of people who are interested in working with highly ordered materials like single crystals would appreciate making really easily," he says. "Besides making flexible devices, it's just going to open up a field for anybody who wants to work with single crystals."

## Scientists Evade the Heisenberg Uncertainty Principle

State-of-the-art sensors, such as MRIs and atomic clocks, are capable of making measurements with exquisite precision. MRI is used to image tissues deep within the human body and tells us whether we might suffer from an illness, while atomic clocks are extremely precise timekeepers used for GPS, internet synchronisation, and long baseline interferometry in radio-astronomy. One might think these two instruments have nothing in common, but they do: both technologies are based on precise measurement of the spin of the atom, the gyroscope-like motion of the electrons and the nucleus. In MRI, for example, the pointing angle of the spin gives information about where in the body the atom is located, while the amount of spin (the amplitude) is used to distinguish different kinds of tissues. Combining these two pieces of information, the MRI can make a 3D map of the tissues in the body.

The sensitivity of this kind of measurement was long thought to be limited by Heisenberg's uncertainty principle, which states that accurately measuring one property of an atom puts a limit to the precision of measurement you can obtain on another property. For example, if we measure an electron's position with high precision, Heisenberg's principle limits the accuracy in the measurement of its momentum. Since most atomic instruments measure two properties (spin amplitude and angle), the principle seems to say that the readings will always contain some quantum uncertainty. This long-standing expectation has now been disproven, however, by ICFO researchers Dr Giorgio Colangelo, Ferran Martin Ciurana, Lorena C. Bianchet and Dr Robert J. Sewell, led by ICREA Professor at ICFO Morgan W. Mitchell. In their article 'Simultaneous tracking of spin angle and amplitude beyond classical limits,' published in *Nature*, they describe how a properly designed instrument can almost completely avoid quantum uncertainty.

The trick is to realise that the spin has not one but two pointing angles, one for the north-east-south-west direction, and the other for the elevation above the horizon. The ICFO team showed how to put nearly all of the uncertainty into the angle that is not measured by the instrument. In this way they still obeyed Heisenberg's requirement for uncertainty, but hid the uncertainty where it can do no harm. As a result, they were able to obtain an angle-amplitude measurement of unprecedented precision, unbothered by quantum uncertainty.

Professor Mitchell uses a solid analogy to state that "To scientists, the uncertainty principle is very frustrating—we'd like to know everything, but Heisenberg says we can't. In this case, though, we found a way to know everything that matters to us. It's like the Rolling Stones song: You can't always get what you want /But if you try sometimes you just might find /You get what you need."

In their study, the ICFO team cooled down a cloud of atoms to a few micro-degrees Kelvin, applied a magnetic field to produce spin motion as in MRI, and illuminated the cloud with a laser to measure the orientation of the atomic spins. They observed that both the spin angle and uncertainty can be continuously monitored with a sensitivity beyond the previously expected limits, although still obeying the Heisenberg principle.

As for the challenges faced during the experiment, Colangelo comments that "in the first place, we had to develop a theoretical model to see if what we wanted to do was really possible. Then, not all the technologies we used for the experiment existed when we started: among them, we had to design and develop a particular detector that was fast enough and with very low noise. We also had to improve a lot the way we were 'preparing' the atoms and find a way to efficiently use all the dynamic range we had in the detector. It was a battle against the Dark Side of Quantum, but we won it!"

The results of the study are of paramount importance since this new technique shows that it is possible to obtain even more accurate measurements of atomic spins, opening a new path to the development of far more sensitive instruments and enabling the detection of signals, such as gravitational waves or brain activity, with unprecedented accuracy.

## Secrets of Ancient Egypt May Spark Better Fuel Cells for Tomorrow's Cars

To make modern-day fuel cells less expensive and more powerful, a team led by John Hopkins chemical engineers has drawn inspiration from the ancient Egyptian tradition of gilding.

Egyptians artists at the time of King Tutankhamun often covered cheaper metals (copper, for instance) with a thin layer of a gleaming precious metal such as gold to create extravagant masks and jewelry. In a modern-day twist, the Johns Hopkins-led researchers have applied a tiny coating of costly platinum just one nanometer thick—about 1/100,000th the diameter of a human hair—to a core of much cheaper cobalt. This microscopic marriage could become a crucial catalyst in new fuel cells that generate electric current for powering cars and other machines.

The new fuel cell design would save money because it would require far less platinum, a very rare and expensive metal that is commonly used as a catalyst in present-day fuel-cell electric cars. The researchers, who published their work earlier this year in *Nano Letters*, say that by making electric cars more affordable, this innovation could curb the emission of carbon dioxide and other pollutants from gasoline- or diesel-powered vehicles.

"This technique could accelerate our launch out of the fossil fuel era," said Chao Wang, a Johns Hopkins Assistant Professor of chemical and biomolecular engineering and senior author of the study. "It will not only reduce the cost of fuel cells. It will also improve the energy efficiency and power performance of clean electric vehicles powered by hydrogen."

In their article, the authors tipped their hats to the ancient Egyptian artisans who used a similar plating technique to give copper masks and other metallic works of art a lustrous final coat of silver or gold. "The idea," Wang said, "is to put a little bit of the precious treasure on top of the cheap stuff."

He pointed out that platinum, frequently used in jewelry, also is a critical material in modern industry. It catalyses essential reactions in activities ranging from petroleum processing and petrochemical synthesis to emission control in combustion vehicles, as well as being used in fuel cells. But, he said, platinum's high cost and limited availability have made its use in clean energy technologies largely impractical— until now.

"There's a lot more cobalt out there than platinum," said lead author and Johns Hopkins post-doctoral fellow Lei Wang (not related to Chao Wang). "We've been able to significantly stretch the benefits of platinum by coating it over cobalt, and we even managed to enhance the activity of platinum at the same time."

Earlier attempts to plate precious metals on non-precious materials were largely stymied by galvanic replacement reactions—oxidation of the non-precious metal. In this study, the team successfully suppressed such reactions by introducing carbon monoxide, a gas molecule that strongly binds to cobalt, protecting it from oxidation.

Not only did the cobalt-platinum nanoparticles reduce the usage of platinum; they performed almost 10 times better than platinum alone. The researchers said this enhanced catalytic activity resulted from both the maximized exposure of platinum atoms on the surface and from interactions between the two metals. "The intimate contact between cobalt and platinum gives rise to compressive strain," Lei Wang said. "It shortens the distance between platinum atoms and makes the chemical reactions more feasible on the surface."

Because platinum and other rare metals play key roles in many industrial applications, the implications of this work extend beyond fuel cells. Currently, the team is working on adapting their technique to other precious metals and non-precious substrates. New developments will target further applications of such materials in chemical conversions of hydrocarbons.

"Many reactions that depends on precious metal catalysts could be rendered cheaper and more effective by taking advantage of our technology," Chao Wang said. "At a time when we are becoming painfully aware of the limits of our non-renewable sources of energy and materials, this technique points us in a very welcome new direction."

## Single Atom Memory: The World's Smallest Storage Medium

One bit of digital information can now be successfully stored in an individual atom, according to a study just published in *Nature*. Current commercially-available magnetic memory devices require approximately one million atoms to do the same. Andreas Heinrich, newly appointed Director of the Center for Quantum Nanoscience, within the Institute of Basic Science (IBS, South Korea), led the research effort that made this discovery at IBM Almaden Research Center (USA). This result is a breakthrough in the miniaturisation of storage media and has the potential to serve as a basis for quantum computing.

Disks coated with a magnetised layer of metal allow our computers to store files in the form of bits, each with the value of either 1 or 0. A certain direction of magnetisation corresponds to the 0 bit, the other direction to the 1 bit. While at the moment small areas of the disk, of around a million atom, correspond to each digital bit of information, this research went way beyond this and utilised the smallest amount of matter usable for this purpose: one atom.

In this study, scientists worked with a tool, called Scanning Tunneling Microscope (STM), which has a special tip that enables the user to view and move individual atoms, as well as to apply a pulse of electrical current to them. They used this electric pulse to change the direction of magnetisation of individual holmium atoms. By doing that, the team could write a memory of either 1 or 0 in a single holmium atom as well as swap the two.

A quantum sensor, designed by Heinrich's team and currently unique worldwide, was used to read the memory stored in the holmium atom. It consists of an iron atom placed next to the holmium atom. Using this technique, as well as another one, called tunnel magnetoresistance, the researchers could observe that holmium maintains the same magnetic state stably over several hours.

Then, when Heinrich's team of researchers tried to use two holmium atoms instead of one, they made another surprising discovery. Placing holmium atoms even one nanometer apart did not impact their ability to store information individually. This came as a surprise, since it was expected that the magnetic field from one atom would impact its neighbour. To put this scale into perspective, if a nanometer were blown up to the diameter of a typical human hair, the hair would have a diameter equivalent to the length of a school bus in comparison.

In this way, the scientists could build a two bit device with four possible types of memory: 1-1, 0-0, 1-0 and 0-1 clearly distinguished by the iron sensor.

Moore's Law predicted that the amount of data that can be stored on a microchip would double every 18 months and indeed this happened for decades. The last model electronic devices are always smaller and more powerful than the previous one. However, as devices become smaller and smaller, since atoms are so close to each other, new interfering quantum properties begin to manifest and cause problems. The impossibility of keeping up with further miniaturisation, brought experts to talk about the death of Moore's Law.

Interestingly, holmium atoms seem to escape this fate, for still unknown reasons. "There are no quantum mechanical effects between atoms of holmium. Now we want to know why," points out Heinrich. Holmium atoms can be arranged very closely together, so the storage density using this single-atom technique could be very high. He continues: "We have opened up new possibilities for quantum nanoscience by controlling individual atoms precisely as we want. This research may spur innovation in commercial storage media that will expand the possibilities of miniaturising data storage."

Heinrich is one of the few in the world using this tool to measure and change the properties of individual atoms. He plans to significantly expand on this research at his newly created IBS research centre, located at Ewha Womans University in Seoul.

## Stress May Protect, at Least in Bacteria

Antibiotics harm bacteria and stress them. Trimethoprim (TMP), an antibiotic, inhibits the growth of the bacterium Escherichia coli and induces a stress response. This response also protects the bacterium from subsequent deadly damage from acid. Antibiotics can therefore increase the survival chances of bacteria under certain conditions. This is shown in a study by researchers at the Institute of Science and Technology Austria (IST Austria), carried out by Karin Mitosch, Georg Rieckh and Tobias Bollenbach, which was published in the journal *Cell Systems.*

Bacteria often encounter harsh environmental conditions: pathogens, for example, have to withstand acidity in the stomach. A specific stress response may help them to survive such stressful conditions. At the same time, the response to a specific stress factor may also protect the bacterium from another stress factor; this is known as cross-protection. In their study, first author and Ph.D student Karin Mitosch and colleagues investigate whether the stress response to antibiotics can also provide such cross-protection.

Antibiotics, i.e., drugs that kill bacteria or inhibit their growth, can also activate stress response genes. So far, it has been unclear whether this stress response may also protect bacteria against other environmental influences. To investigate this question, the researchers exposed the bacterium Escherichia coli to low concentrations of four different antibiotics. At the same time, they measured how transcription changes across the entire genome of the bacterium in response to the antibiotics. Transcription is the copying of DNA into mRNA, which in turn provides the instructions for protein production.

One of the antibiotics investigated, trimethoprim (TMP), induces a rapid acid stress response, which is very variable from one bacterial cell to another. Those bacterial cells with a strong stress response are better protected from a subsequent acid attack. When the researchers exposed bacterial populations to an extremely acidic hydrochloric acid solution, the bacteria died rapidly: their survival is measured as 'half-life'— similar to the decay of radioactive materials— and amounts to only about 30 minutes. When the researchers placed the bacterial populations into a solution containing low concentrations of TMP first, and only later into the hydrochloric acid solution, the half-life triples to over 100 minutes.

Mitosch and colleagues elucidated the biochemical mechanism on which this cross-protection is based. TMP leads to a depletion of adenine-nucleotides, an important building block of DNA and energy carrier in the cell. This depletion in turn induces the acid stress response. Karin Mitosch explains the importance of their findings: "We propose a way how to find cross-protection between antibiotics and other stress factors. This is important, as our study gives an example for how antibiotics can influence the survival chances of bacteria in different environmental conditions. If we understand which cross-protection exists, targeted strategies may be developed that enhance the effect of antibiotics in the treatment of diseases."

## Tracking a Solvation Process Step by Step

Chemists of Ruhr-Universität Bochum tracked with unprecedented spatial resolution how individual water molecules attach to an organic molecule. They used low-temperature scanning tunneling microscopy to visualise the processes at a scale smaller than one nanometre. This allowed them to investigate the phenomena of hydrophilicity and hydrophobicity at the molecular level, i.e., why certain parts of organic molecules attract or repel water.

"The results are an important step on the path to understanding solvation processes, that is, how substances dissolve in water," explains Karsten Lucht of the Bochum Chair of Physical Chemistry I. He reports the results with the team led by Professor Dr Karina Morgenstern and colleagues from the Chair of Organic Chemistry II in the journal *Angewandte Chemie*. The scientists cooperate in the excellence cluster Ruhr Explores Solvation, or Resolv for short.

The aim of the cluster is to understand how solvents affect the reactions in solution and the use of solvents to control reactions.

### Tracking Water Accumulation Step by Step

As an organic molecule, the researchers used an azo dye that consists of two carbon rings with attached functional groups that are polar, i.e., slightly positively or negatively charged. They deposited the molecules on a gold single crystal and cooled the system to six Kelvin. Then they added individual water molecules step by step and observed where these attached to the dye.

The first water molecules preferred to attach themselves to the polar functional groups. When the researchers increased the amount of water, the newly added molecules attached themselves to the water molecules that were already bonded. "Our experiments show that hydrophilicity and hydrophobicity can be traced back to molecular level," says Karina Morgenstern. The water molecules avoided non-polar areas of the molecule, polar areas were preferred.

### Three Complementary Procedures

The processes that were observed here with scanning tunneling microscopy are usually investigated spectroscopically or with molecular dynamic simulations. However, the first method does not provide spatial information, and the latter is based on assumptions due to the size of the system. "Every method has its value," explains Karsten Lucht. "The three approaches complement each other."

## Where Does Laser Energy Go After Being Fired into Plasma?

An outstanding conundrum on what happens to the laser energy after beams are fired into plasma has been solved in newly-published research at the University of Strathclyde.

The study discovered that the same forces that produce a bubble in plasma in the laser-plasma wakefield accelerator produce two additional low-energy but high-charge electron beams simultaneously with a low charge high energy beam. These high charge beams can have a thousand times more charge than the high energy beam.

Plasma, the state in which nearly all of the universe exists, can support electric fields that are 1,000 to 10,000 times higher than in conventional accelerators, simply by separating the positive and negative charged particles that makes up the plasma medium, which is quasi-neutral.

This can easily be achieved using an intense laser pulse, the light pressure of which pushes electrons out of its way, leaving behind the much heavier ions which remain in place and exert an attractive force on the displaced electrons. The displaced electrons then oscillate around the stationary ions resulting in a wake behind the laser pulse, in a similar manner to the wake behind a boat.

Because the laser pulse travels at a velocity close to that of light in vacuum, the wake can track and accelerate charged particles rapidly to very high energies, over extremely short lengths.

The research paper, entitled 'Three electron beams from a laser-plasma wakefield accelerator and the energy apportioning question,' has been published in *Scientific Reports.*

Professor Dino Jaroszynski, of Strathclyde's Department of Physics, led the study. He said: "The intense laser pulse we used, and the acceleration of the wake it creates, lead to a very compact laser wakefield accelerator, which is millimetres long, rather than tens of metres long, for an equivalent conventional accelerator. The plasma wake forms into something like a bubble-shaped, laser-powered miniature Van de Graaf accelerator, which travels at close to the speed of light.

"Some of the laser energy is converted to electrostatic energy of the plasma bubble, which has a diameter of several microns. Conventional accelerators store their microwave energy in copper or superconducting cavities, which have limited power-carrying capability.

"An interesting conundrum that has not been considered before is the question of where laser energy goes after being deposited in plasma. We know where some of this energy goes because of the presence of high-energy electrons emitted in a narrow, forward directed beam.

"One of these beams is emitted by a sling-shot action into a broad forward-directed cone, with several MeV (mega electron volt) energies and nanocoulomb-level charge. Paradoxically, another beam is emitted in the backward direction, which has similar charge but an energy of around 200 keV (kilo electron volt). These beams carry off a significant amount of energy from the plasma bubble.

"It is interesting to observe that answering a very basic question — where does the laser energy go? — yields surprising and paradoxical answers. Introducing a new technology, such as the laser-wakefield accelerator, can change the way we think about accelerators. The result is a very novel source of several charge particle beams emitted simultaneously.

"My research group has shown that the wakefield accelerator produces three beams, two of which are low energy and high charge, and the third, high energy and low charge."

Dr Enrico Brunetti, a Research Fellow in Strathclyde's Department of Physics and a member of the research group, said: "These beams can provide a useful high flux of electrons or bremsstrahlung photons over a large area, which can be used for imaging applications, or for investigating radiation damage in materials. If not properly dumped, they can, however, have undesirable side-effects, such as causing damage to equipment placed close to the accelerator.

"This is a particular concern for longer accelerators, which often use plasma wave guides based on capillaries to guide the laser beam over long distances. These low energy, high charge beams also carry a large amount of energy away from the plasma, setting a limit to the efficiency of laser-wakefield accelerators.

"This is an issue which needs to be taken into account in the future design and construction of laser-wakefield accelerators."

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