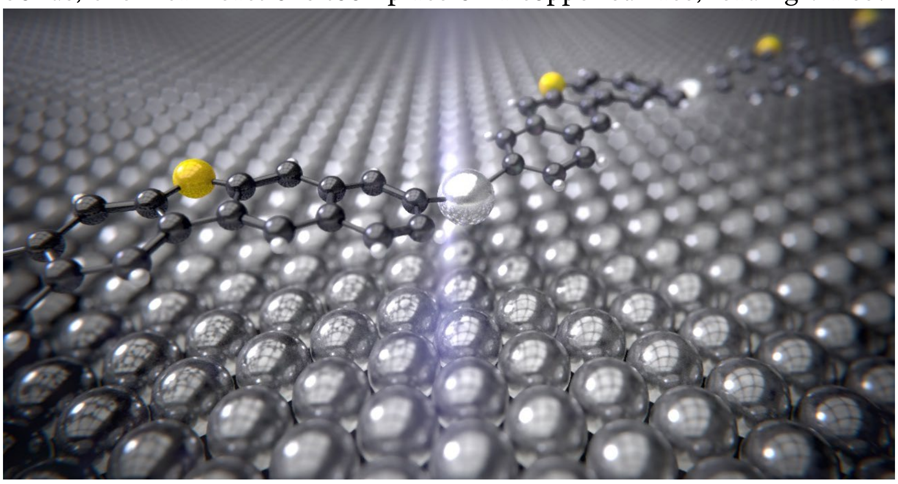
Solving riddles with the AFM

On September 6 this year, Professor Christoph Gerber, Professor Carl Quate and Dr Gerd Binnig received the Kavli Prize in Nanoscience. The formal ceremony took place in Oslo, in the presence of Crown Prince Haakon of Norway, and recognized the prizewinners' invention and development of the atomic force microscope (AFM) 30 years ago. Since then, the AFM has become an important tool for nanoscience research, with a wide range of uses. This is reflected in some of the publications by SNI members that have appeared in recent weeks in prestigious scientific journals such as "Nature".

Observing chemical reactions

In the last few weeks and months, scientists working with Professor Ernst Meyer and Dr Shigeki Kawai have published papers describing their use of a high-resolution atomic force microscope with a carbon monoxide tip to track and understand chemical reactions. They have been able, for example, to watch a silver catalyst at work for the first time. During the so-called Ullmann reaction, silver atoms catalyze the bond between two carbon atoms. The researchers' observations allowed them not only to work out how the reaction takes place, but also to calculate the energy turnover involved. This may make it possible to find ways of optimizing this long-established and often implemented reaction.

In another study, copper rather than silver functioned as the catalyst. Starting with a molecule in which three benzene rings were bound together by triple bonds, chemical reactions took place on a copper surface, leading via several steps to the production of new aromatic hydrocarbon compounds that had never previously been synthesized in solution. Comparative computer calculations yielded the precise molecular structure of the compounds, which perfectly matched the microscopic images.



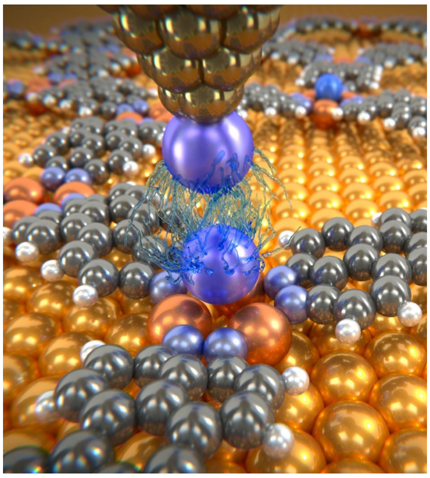
The intermediate product of the Ullmann reaction with the silver catalyst (silver) between the carbon rings (black) and sulfur atoms (yellow) curves like a bridge over the silver surface.

Measuring the tiniest forces

Using atomic force microscopy, scientists from Ernst Meyer's and Professor Thomas Jung's group have succeeded for the first time in measuring the very weak Van der Waals forces between individual atoms. To do this, they fixed noble gas atoms in a molecular network and evaluated the interactions with a single xenon atom placed on the tip of a cantilever in the atomic force microscope. As expected, the forces were dependent on the distance between the two atoms, but sometimes they were significantly greater than theoretical calculations had suggested.

Evidence of exotic particles

Scientists from the SNI and the Department of Physics at Basel are using atomic force microscopy not only to study and understand chemical processes: With the different microscopes available, which can be



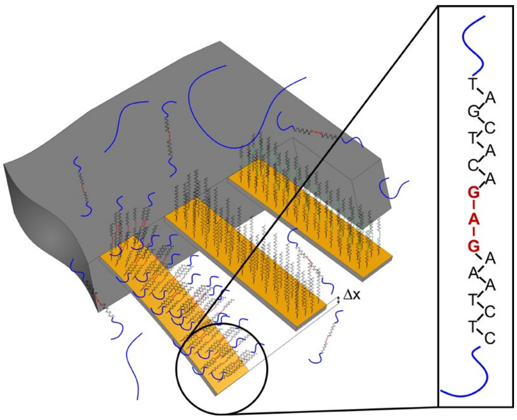
Rare gas atoms deposited on a molecular network are investigated with a probing tip, which is decorated with a xenon atom. The measurements give information about the weak van der Waals forces between these individual atoms.

used in a variety of ways, it is also possible to observe physical phenomena in the most precise detail. Professor Ernst Meyer's group and the theoretical physicists grouped with Professor Jelena Klinovaja and Professor Daniel Loss are working together using AFM to find experimental proof of the existence of so-called Majorana fermions, which are also their own anti-particles. These exotic particles were first described around 75 years ago by the physicist Ettore Majorana. Interest in them has grown hugely since then, as they may have a role to play in producing a quantum computer. The Majoranas are already well described in theoretical terms. However, studying them and finding experimental proof of their existence has proved difficult, as they always occur in pairs, but usually combine to form a normal electron. Very ingenious combinations and arrangements of different materials are therefore needed to produce two Majoranas and keep them apart.

Cancer diagnosis

AFM employs cantilevers equipped with a sharp tip to scan samples. The inventor of AFM Christoph Gerber is now using these cantilevers for diagnostic purposes. Gerber's team coats the cantilevers with different molecules, depending on what is needed. In a study published recently in "Nano Letters", he presents the use of cantilevers in initial clinical trials to help treat malignant melanoma.

To do this, Gerber's team coats the cantilevers with a recognition sequence for a gene mutation exhibited by 50 percent of all patients with malignant melanoma. RNA is then isolated from patients' tissue samples and applied to the cantilevers. If the genetic change is present, the RNA binds to the recognition sequence on the cantilever. The resulting surface stress causes this to bend, providing the scientists with a clear signal that indicates the presence of the mutation. As a potential treatment is available for patients who exhibit this genetic change, a quick and inexpensive test of this kind is highly valuable.



The cantilever on the left bears the recognition sequence for the target mutation. If this is present in the sample being tested, the corresponding segment of RNA binds to the cantilever, causing the latter to bend. This can be measured, providing clear evidence that the genetic change is present.

Development brings new applications

Christoph Gerber and his colleagues laid the foundations for this and many other research studies 30 years ago. Since then, there has been ongoing development of AFM, and today it can be used in a huge variety of ways. For example, Professor Patrick Maletinsky is placing diamonds with nitrogen-vacancy centers in atomic force microscopes as quantum sensors, enabling him to generate images of magnetic fields in superconductors at a resolution not yet seen. In a recent issue of "Nature Nanotechnology", Maletinsky's team describe their success in using this new kind of AFM for the first time in cryogenic conditions, at temperatures of around 4 Kelvin (-269,15 °C). With it, they were able to image magnetic stray fields of vortices in a high-temperature superconductor with unprecedented precision.

Argovia Professor Martino Poggio is also working to develop a new type of AFM, as he describes in "Nature Nanotechnology". To do so, Poggio's team are using nanowires as tiny sensors, which allows them – unlike with traditional devices – to measure both the magnitude and the direction of forces. Here the researchers are able to exploit the special mechanical properties of the nanowires, which vibrate at roughly the same frequency along two axes at right angles to each other. Using AFM, the scientists measure the changes in vibration that are triggered by different forces. They therefore use the nanowires as tiny mechanical compass needles indicating both the direction and the magnitude of the surrounding forces.

These are just some examples of research results involving AFM that have been published by SNI members in recent months. “Since AFM was invented, around 350,000 publications have appeared about it,” Christoph Gerber notes. “And it will be fascinating to see how the technology continues to evolve.”

In September, Crown Prince Haakon of Norway awarded Carl Quate, Christoph Gerber, and Gerd Binnig with the Kavli Prize for the invention and development of the AFM (image: Thomas Brun/NTB Scanpix).