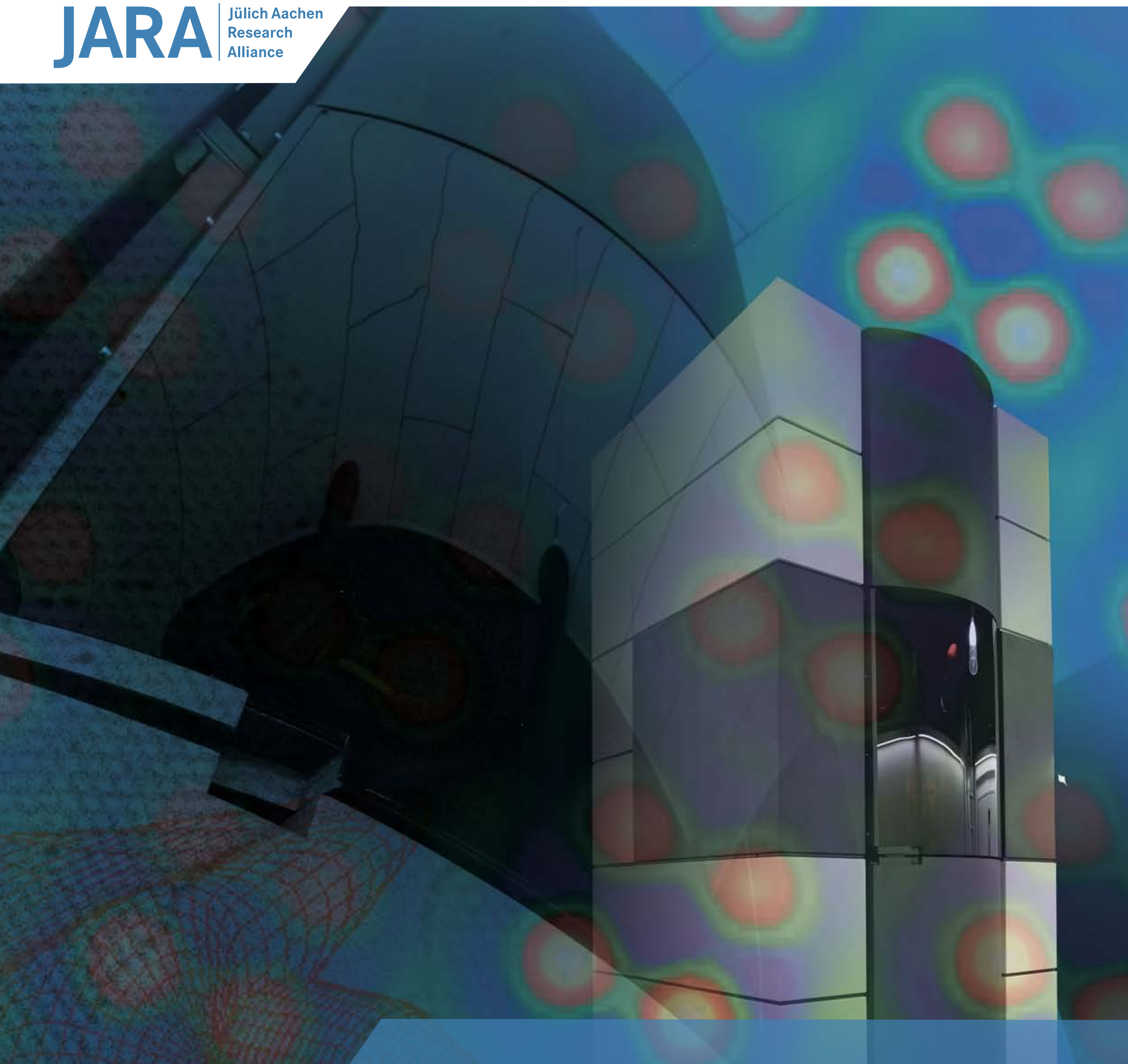
JARA Jülich Aachen Research Alliance



Insight into the World of Atoms

Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons

AN INITIATIVE OF

RWTH AACHEN UNIVERSITY

JÜLICH FORSCHUNGSZENTRUM

Contents

Foreword

Univ.-Prof. Dr.-Ing. Ernst Schmachtenberg, Rector of RWTH Aachen University (l.), and Prof. Dr. Achim Bachem, Chairman of the Board of Directors of Forschungszentrum Jülich.

Microscopy represents one of the major breakthroughs of modern science. Since the early 17th century, scientists have made use of microscopes to make visible what was until then inaccessible to the human eye. The Ernst Ruska-Centre (ER-C) for Microscopy and Spectroscopy with Electrons specializes in the further development of these imaging techniques.

The ER-C's ultrahigh-resolution electron microscopes allow unique insights to be acquired into the world of atoms. These insights are key to innovations, especially in materials research and nanotechnology, because the interplay of individual atoms determines the properties of materials and components. Materials research and nanotechnology, for their part, will be essential for responding to the major questions of our global society: How can we have a sustainable future despite finite raw materials? How can we meet our energy needs in a climate-friendly manner? How can we communicate and share know-how in an energy-efficient way?

Pressing challenges such as these are also driving the Jülich Aachen Research Alliance (JARA). The strategic partnership between RWTH Aachen University and Forschungszentrum Jülich represents a new type of collaboration between a university and a non-academic research institution. The ER-C, which was founded in 2004, is an indispensable part of this alliance, which is unique in Germany. The Centre was a shining example for JARA when it was launched in 2007, demonstrating the success of efforts to eliminate barriers between large-scale research institutions and universities, to jointly define research objectives and jointly make investments.

However, the ER-C is not just open to researchers in Aachen and Jülich. It gives scientists from universities, research institutions and industry access to the highest-resolution electron microscopes of our time. For fifty percent of the usage time, the microscopes are available to external scientists. This is stipulated in an agreement with the German Research Foundation (DFG), a major funder of the ER-C. The DFG also nominates a panel of experts that reviews applications submitted by external scientists. This concept of the ER-C as the first national user centre for ultrahigh-resolution electron microscopy has proved to be extraordinarily successful. With the new PICO microscope in a new building, the way has been paved for the ER-C to continue to maintain its internationally leading position.

Prof. Dr.-Ing. Ernst Schmachtenberg   Prof. Dr. Achim Bachem

Unique Insights into the Nanoworld

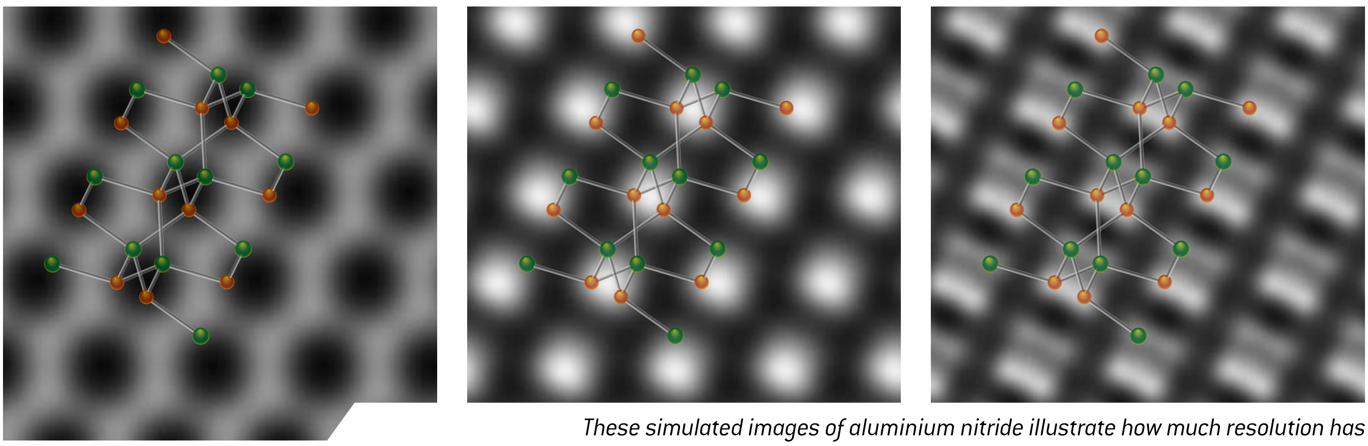
The arrangement of atoms inside a material determines its electrical, magnetic, optical and mechanical properties. An understanding of atomic structure in materials is therefore key to understanding fundamental physical processes and developing new applications. For both scientific and technological progress, the ability to visualize and study the details of the atomic world is essential. Modern electron microscopes make this possible.

A simple example can be used to illustrate the tiny dimensions that are studied by scientists using state-of-the-art electron microscopes. In order to visualize the atoms in a human hair, which has a diameter of only 1/20 of a millimetre, one would need to blow up its cross-sectional area to the dimensions of a football pitch. The thickness of a blade of grass on the pitch would then correspond to the diameter of one atom.

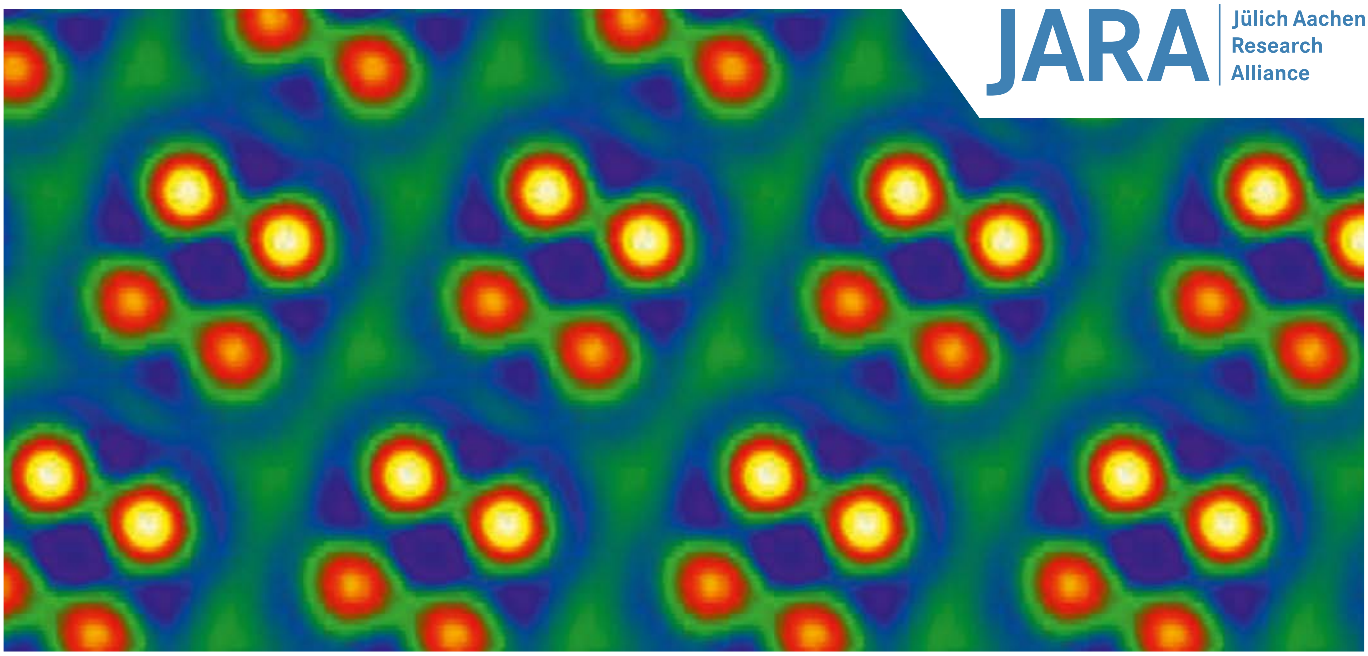
Units of Length

Metre	One	10^{0}	1
Millimetre	One thousandth	10^{-3}	0.001
Micrometre	One millionth	10^{-6}	0.000 001
Nanometre	One billionth	10^{-9}	0.000 000 001
Picometre	One trillionth	10^{-12}	0.000 000 000 001

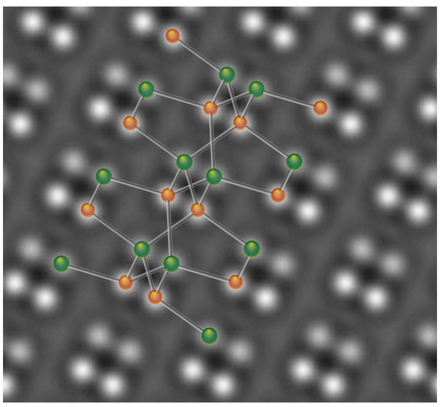
Whereas a conventional optical microscope can be used to visualize bacteria, it is not able to provide images of atoms, which are about ten thousand times smaller. This is because the wavelength of light limits the resolution of the microscope. Resolution is a measure of how far apart features in a specimen can be from each other, yet still be visualized separately.



These simulated images of aluminium nitride illustrate how much resolution has improved with each generation of electron microscopes from 1992, 1998 and 2005 up to the present day (from left to right).



An electron microscope uses electrons instead of light. The electron beam is guided using magnetic fields, which play a similar role to glass lenses in an optical microscope. The wavelength of the electrons is so small that it should be possible to image atoms without difficulty. However, after electron microscopy was invented in the 1930s, attempts to visualize atoms remained unsuccessful for decades as a result of lens imperfections, or aberrations, that could not be corrected. In an optical microscope, divergent lenses can be used to compensate for the aberrations of convergent lenses. However, divergent lenses cannot be built for electrons using rotationally symmetric magnetic fields.



Only PICO makes it possible to actually recognize the atoms in this material. The atoms are shown as green and red spheres as an aid to recognition.

In the 1990s, researchers at the Technische Universität Darmstadt, the European Molecular Biology Laboratory (EMBL) in Heidelberg, and Forschungszentrum Jülich found a solution to this dilemma. They developed a corrector that could eliminate the effects of "spherical aberration" for electrons (see p. 10). The world's first such transmission electron microscope was put into operation at Forschungszentrum Jülich in 1998. This prototype instrument is now on display at the Ernst Ruska-Centre (ER-C). Since 2004, transmission electron microscopes that are equipped with spherical aberration correctors have been available commercially, with all leading electron optics manufacturers now offering this capability. In 2006, two TITAN 80–300™ microscopes from the Dutch-US company FEI were installed at the ER-C. They are able to visualize atomic structures with a resolution of 80 picometres.

In 2011, the ER-C took delivery of a PICO transmission electron microscope, whose resolution is 50 picometres. It is one of only two such microscopes in the world that can correct for an additional lens aberration – chromatic aberration (see p. 11). Apart from improving the resolution, the ability to correct for chromatic aberration also increases the precision with which atomic distances and displacements in materials can be measured, from 5 picometres to 1 picometre.

With the PICO microscope, both scientists at the ER-C and external users can approach closer to the physical limit of electron optics for observations at the nanoscale. However, this capability is not an end in itself. Picometre precision measurements are essential to be able to control and optimize components in nanoelectronics and nanotechnology. Scientists need insight into the world of atoms and the processes that take place on this scale to develop new materials for areas such as information technology and energy materials.

Prof. Rafal Dunin-Borkowski (l.) and Prof. Joachim Mayer

Rafal Dunin-Borkowski ...

... who is originally from the UK, joined Forschungszentrum Jülich in 2011, where he heads the Institute for Microstructure Research at the Peter Grünberg Institute. He is also a director of the ER-C. Previously, Prof. Dunin-Borkowski was the founding director of the Center for Electron Nanoscopy at the Technical University of Denmark in Lyngby.

Joachim Mayer ...

... is a full professor of Microstructural Analysis and head of RWTH Aachen University's Central Facility for Electron Microscopy. Since the founding of the Ernst Ruska-Centre in 2004, he has been one of the Centre's two directors.

"In-depth understanding"

Interview with the directors of the Ernst Ruska-Centre

All kinds of methods are available for scientists to obtain information about the structure of the world in the micrometre and nanometre range. What can electron microscopy do that other methods cannot?

Mayer: Electron microscopy was invented in order to overcome the limits of optical microscopy. In fact, you wouldn't be able to visualize the transistors installed in today's laptops with an optical microscope, because they are too small. You also wouldn't be able to use an optical microscope to visualize the defects that – when they move – are responsible for the plastic deformation of many materials. These are just two examples that demonstrate our need for electron microscopy to investigate the way in which components function or to study the properties of materials.

Dunin-Borkowski: Transmission electron microscopy provides information about the internal structure of materials. This distinguishes it from methods such as scanning tunnelling and atomic force microscopy. These two techniques are also commonly used to investigate the nanoworld, although they visualize only the surfaces of materials.

So you buy the best possible electron microscopes, prepare a material specimen and then obtain the information you need. Is it really that easy?

Dunin-Borkowski: No, it isn't. High-resolution electron microscopy is certainly not a technology that functions perfectly just by pressing a button. For this reason, having a top-class instrument is no guarantee that you will perform top-class research. You need a great deal of knowledge and expertise to obtain and interpret images. One of the Ernst Ruska-Centre's key features is the development of methods for understanding lens aberrations and interpreting images. There are very few other centres in the world that invest so much in this area. We have experienced scientists with an in-depth understanding of electron optics and quantum mechanics.

Why do you need so much theoretical expertise in quantum mechanics and other areas?

Mayer: When electrons hit the specimen in the microscope, their interaction with matter is characterized by quantum mechanics. This means that you need quantum mechanics to evaluate electron microscopy studies quantitatively, meaning correctly and completely in terms of numbers.

Dunin-Borkowski: In a microscope in which the lens aberrations are corrected, the electrons pass through a very complicated system of magnetic poles controlled by hundreds of power supply units. You have to know how the electrons are influenced by these elements in order to improve the quality of the resulting image.

What do you expect to gain from PICO, one of two such electron microscopes worldwide in which chromatic aberration is also corrected?

Dunin-Borkowski: Once electron microscopes that corrected spherical aberration became available, new methods were developed at the Ernst Ruska-Centre for the reliable evaluation of the ultrahigh-resolution data. Now, with PICO, we have an electron microscope in which chromatic aberration is also corrected. We anticipate that we will be able to repeat the success story in the way we develop methods. PICO will enable us to not only improve image resolution to about 50 picometres, but it will also permit us to improve the precision with which the positions of atomic columns in materials can be determined. The advantage of the improved resolution will become particularly apparent when we use relatively low accelerating voltages. This may be required for soft or biological materials, which are frequently sensitive to radiation.

Members of the ER-C team (from the left): Dr. Karsten Tillmann, Dr. Juri Barthel, Marita Schmidt and Dr. Andreas Thust.

Apart from the new microscope and the methodological expertise of the scientists, what makes the Ernst Ruska-Centre so special?

Mayer: The new PICO is part of the world's most impressive collection of aberration-corrected electron microscopes. It also includes two FEI Titan 80–300 microscopes manufactured in 2007 and the world's first prototype of an aberration-corrected electron microscope. By the end of this year, these four microscopes will be joined by another world-class electron microscope.
What also sets the Ernst Ruska-Centre apart is the fact that the microscopes are used to meet global challenges such as the development of materials for a climate-friendly energy supply or energy-efficient information technology. We are performing research on materials for CO_2-free power plants and for more powerful data storage systems.

Dunin-Borkowski: With its electron microscopes, which are among the world's best-performing instruments, and its excellent scientists, the Ernst Ruska-Centre is able to attract researchers from Germany, Europe and the rest of the world to investigate their scientific questions and applications.

The Ernst Ruska-Centre is part of the Jülich Aachen Research Alliance (JARA). Why is it important for the Centre to be set up as a joint facility of RWTH Aachen University and Forschungszentrum Jülich?

Mayer: One research institution alone, even one the size of Forschungszentrum Jülich, cannot justify the acquisition of several aberration-corrected electron microscopes. After all, a microscope of this sort costs between four and seven million euros.
Ultimately, the aim is to get as much use out of the microscopes as possible. The only way to do this is to employ scientists who work on methods, along with scientists who contribute research projects and applications. Early-career scientists also need to be trained to use the technology. One research institution alone would find it difficult to do this by itself. Within JARA, RWTH Aachen University and Forschungszentrum Jülich share what each institution can do best, which generates real added value.

In what direction will the Ernst Ruska-Centre continue its development?

Mayer: First of all, I think it's important to note that the results that have been obtained and the user statistics provide impressive evidence that the ER-C's concept has been extremely successful. We are a leading centre on the international level. Still, there are many directions in which the ER-C is continuing to expand ...

Dunin-Borkowski: For instance, we want to use electron microscopy more often to measure materials or nanocomponents in operation at the atomic level. This is why the next microscope that we will acquire will have more room around the specimen, which will allow us to perform experiments under observation in the electron microscope.
Another path that we are considering: So far, at the ER-C, materials for future information technology have been the primary focus. However, there are a number of research groups from other disciplines that can benefit from high-resolution electron microscopy and the methods that are developed here, for example in the areas of soft, biological or geological materials. At the same time, we can profit from their questions and applications. It would make sense to increase our cooperation with these communities.

Profile of the Ernst Ruska-Centre (ER-C)

With the establishment of the Ernst Ruska-Centre (ER-C), Forschungszentrum Jülich and RWTH Aachen University operate a centre of excellence for atomic-resolution electron microscopy and spectroscopy at the highest international level in close cooperation with the activities of the Jülich Aachen Research Alliance (JARA). The ER-C develops scientific and technical infrastructure and methods for present and future materials research. It is also a national user facility for ultrahigh-resolution electron microscopy. Fifty percent of the available instrument time is allocated to external users from universities, research institutions and industry on the basis of scientific criteria.

The Key to Innovations

Our society must find ways to satisfy our need for energy in a climate-friendly way. We need more energy-efficient but also more powerful methods for transferring and storing information and knowledge. These challenges can only be met with the help of technological innovations. Four examples illustrate how the ER-C's scientists use today's high-performance electron microscopes for innovative research.

Example 1:

Information and communications technologies affect our daily life and the productivity of industry and services. In the future, not only processors but also data storage systems will continue to become smaller, more powerful and more energy-efficient. Today's computer hard drives are based on magnetic materials. By using specially equipped ultrahigh-performance electron microscopes and specialized imaging and analysis techniques, magnetic fields in these types of materials can be visualized "with a resolution of only a few nanometres, a feat that cannot be achieved for magnetic fields inside small crystals with any other method,"

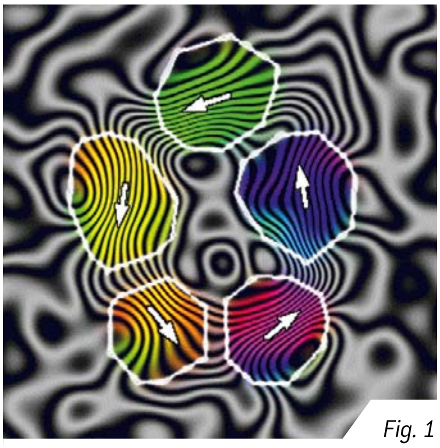


Fig. 1

says Prof. Rafal Dunin-Borkowski, who has advanced electron holography for investigating magnetic materials and brought expertise in this technique to the ER-C. Fig. 1 shows magnetic field lines (black) and their directions (white arrows) in a ring-shaped arrangement of cobalt particles (white borders), each a mere 20 to 30 nanometres in size. The particles influence each other via their magnetic fields. Each particle contains only a single magnetic domain, which can be identified by the mostly uniform colour within the particle. Such self-organized ring-shaped structures are candidates for data storage systems of the future, because they are smaller than many of the storage systems that are used today.

Example 2:

ER-C scientists investigate ferroelectric materials. In contrast to many of the technologies that are currently used for computers' working memories, data stored in such materials can be preserved even after the computer is switched off. The researchers at the ER-C have used a high-resolution electron microscope to observe that the electric dipoles in a ferroelectric material can be turned nearly continuously (Fig. 2). This property permits the formation of tiny triangular "domains" that can form a nanometre-sized "elementary vortex" in which the electric field turns by 360 degrees. Based on this direction of rotation, clockwise or counter-clockwise, a digital bit can be realized in the tiniest space, opening a pathway to achieve a working memory to which nonvolatile data can be written with ultrahigh density.

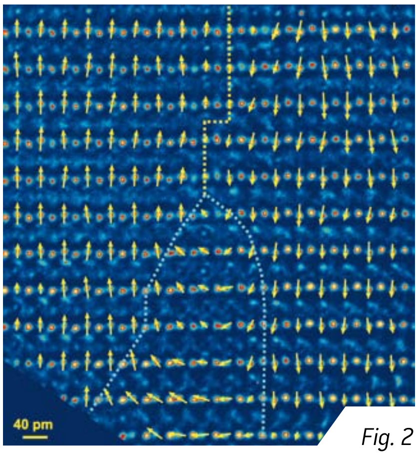


Fig. 2

Example 3:

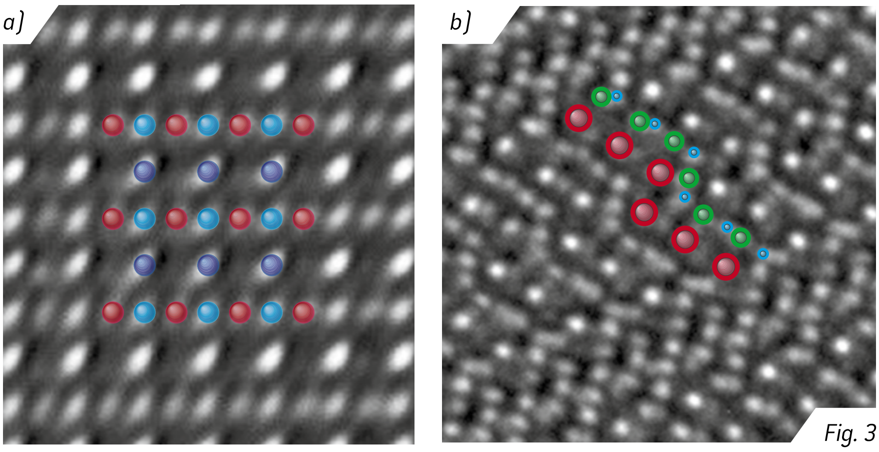


Fig. 3

Coal- and gas-fired power plants are major contributors to global warming due to their carbon dioxide emissions. The emissions could be reduced by separating CO_2 from the gas stream in power plants and then, for example, storing it underground. Scientists from the Jülich Aachen Research Alliance (JARA) are collaborating with universities, research institutions, and industrial partners to work on membranes that can be used to separate gases such as carbon dioxide, hydrogen, or oxygen. With the help of these membranes, methods are being developed that are less energy-intensive than conventional separation methods.

In their search for the most efficient membranes, the researchers fabricate materials using a wide variety of methods. Afterwards, they test how well and how long they function under the conditions prevailing in a power plant. By using the electron microscopes at the ER-C, they are seeking to identify the reasons for the different performance of the materials. This difference is ultimately determined by the arrangement of the atoms, which can be visualized using electron microscopy. The researchers at the ER-C have studied samples of a material called BSCF, which appears to be well suited for separating oxygen and nitrogen at 700 to 900 °C. During their research, they observed that at these temperatures, after several hundred hours, areas form in which the atoms are arranged differently than they were originally (Fig. 3a and b) – with significant consequences for the oxygen conductivity of the material. These observations provide a starting point for improving the potential membrane material. For instance, they may use chemical additives to prevent the atoms from rearranging.

Example 4:

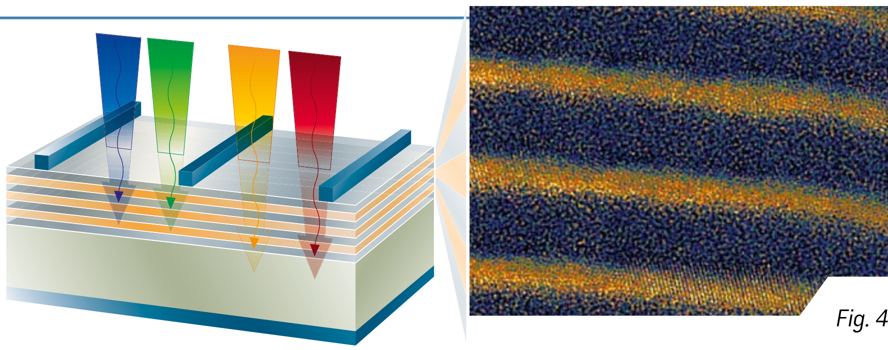
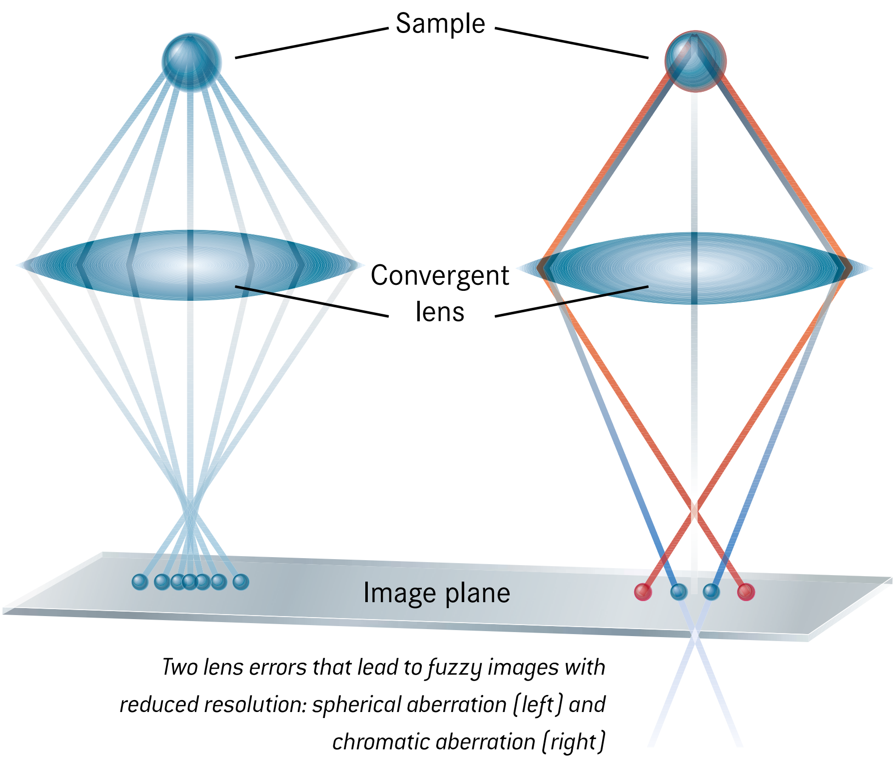


Fig. 4

Solar cells use an effectively inexhaustible energy source – the sun – and generate clean electricity. ER-C researchers are partners in a collaborative project for developing solar cells that optimally harness incoming sunlight. They have used the PICO ultrahigh-resolution microscope to study multi-layered structures, which absorb the blue and green wavelengths of light better than classical solar cells (Fig. 4 left). Fig. 4 right was recorded using inelastically scattered electrons, an imaging mode in which atomic resolution chemical information can be obtained using PICO. Measurement of the individual layer thicknesses as precisely as possible is also significant, as they play a key role in the solar cell's absorption capacity.

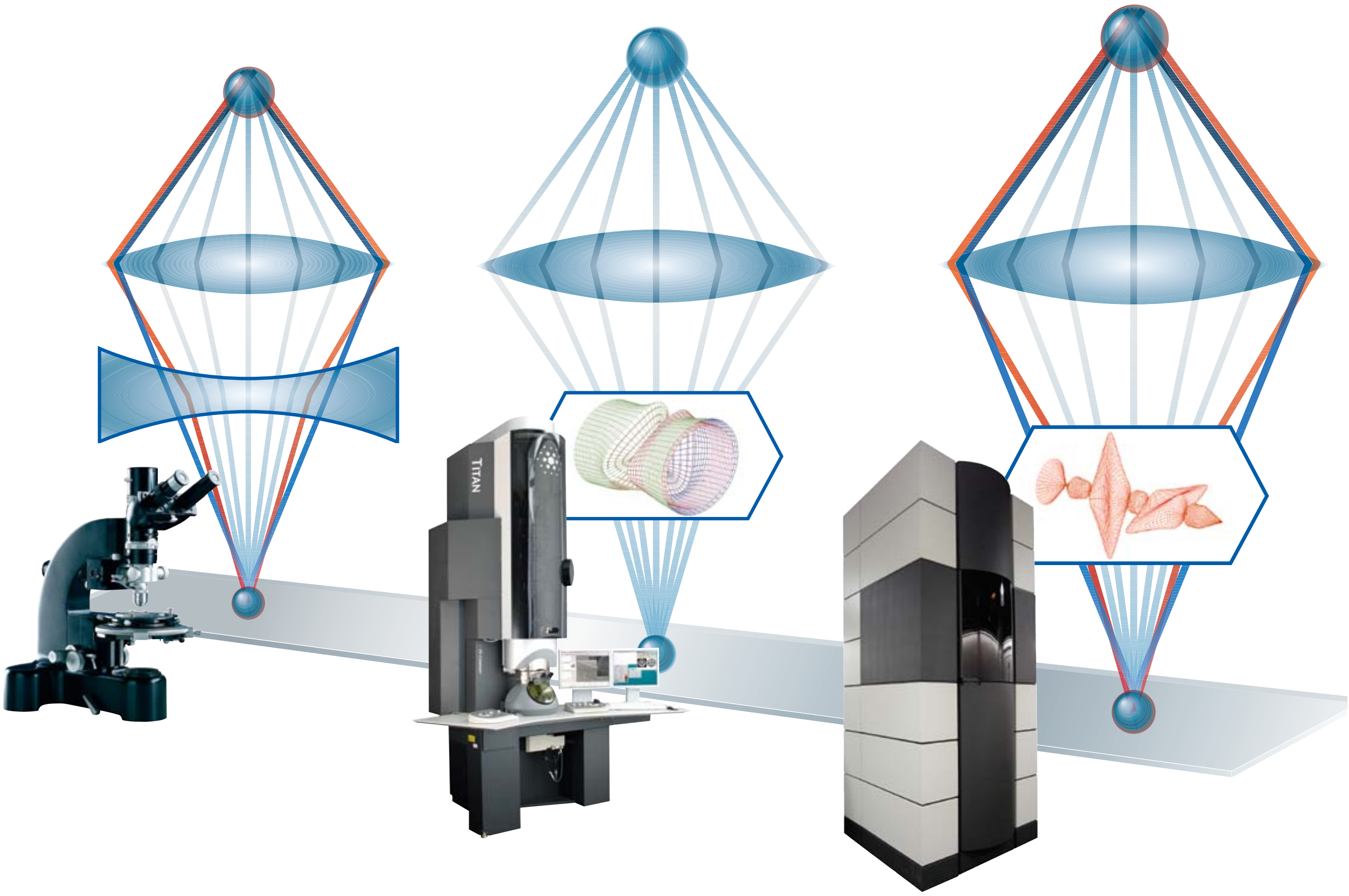
The Know-How Behind Ultrahigh-Resolution Electron Microscopes

Whereas in an optical microscope a beam of electromagnetic radiation – light – illuminates a specimen, in an electron microscope accelerated electrons perform this task. The beam path is similar in both cases. However, in the electron microscope the formation and interpretation of images is much more complicated. Even the correction of electron microscope lens optics does not allow for direct imaging of the world of atoms, as quantum physics plays a key role in these dimensions. Intuitive image interpretation is not always possible and sophisticated computer programs are required for image analysis and simulation.



Two lens errors that lead to fuzzy images with reduced resolution: spherical aberration (left) and chromatic aberration (right)

Rotationally symmetric magnetic fields that serve as lenses in electron microscopes have physically unavoidable imaging errors that are similar to those of glass lenses in optical microscopes. Two of these errors are especially significant. The first of these is referred to as spherical aberration. Beams that travel at large angles to the optical axis and pass through the edges of the lens are focused more strongly than beams that pass through the lens more centrally. This results in blurred images with reduced resolution.



In a light microscope (left), a divergent lens ensures that imaging errors are corrected. Electron microscopes of the most recent generation (centre) can eliminate spherical aberration by means of a hexapole corrector. PICO (right) now uses a system of magnetic and electrostatic multipole elements to also correct chromatic aberration

The second error is chromatic aberration, which refers to the focusing of different wavelengths with different strengths. In optical microscopes, the wavelength of light determines the colour that we perceive and chromatic aberration results in a “colour error” and image blurring. In optical microscopes, both errors can be eliminated by using additional divergent lenses. Approaches for creating divergent lenses for electron beams were only introduced in the late 1990s using “hexapole correctors”. The key elements of such a corrector are two multipoles, in which six (Greek: hexa) magnetic coils surround a central opening for the electron beam. The effect of each of the six superimposed magnetic fields is similar to that of a divergent lens. The corrector can be used to eliminate the spherical aberration that restricts the resolution of the electron microscope. Chromatic aberration is even more difficult to correct, requiring a complicated system of magnetic and electrostatic multipole elements.

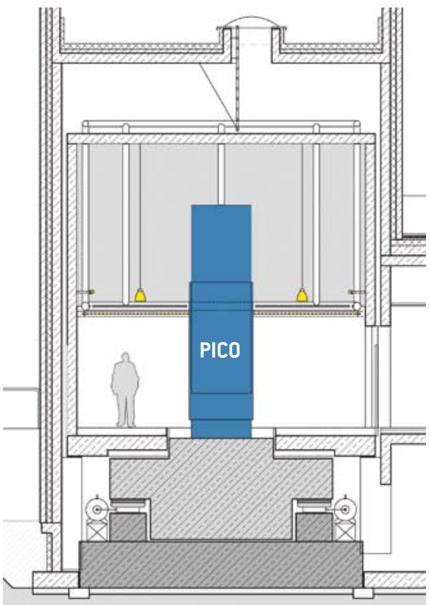
The operation of an aberration corrector for electrons requires dozens of magnetic and electrostatic fields to be precisely coordinated. In order to perform this adjustment, the first step involves measuring the state of the system. This is similar to using a navigation system that must first determine its current location before it can suggest the shortest route to a destination. However, while a sat-nav system requires only coordinates for the longitude and latitude to determine its location, diagnosing lens errors calls for around 30 parameters. Scientists at the Ernst Ruska-Centre have developed ATLAS software to perform this difficult task. This type of computer program is also required because the state of the aberrations in an electron microscope changes over a matter of minutes and sometimes even seconds. There are many reasons for this rapid variation, including minute temperature fluctuations in the microscope column, fluctuations of the voltage source or changes in the position of the specimen.

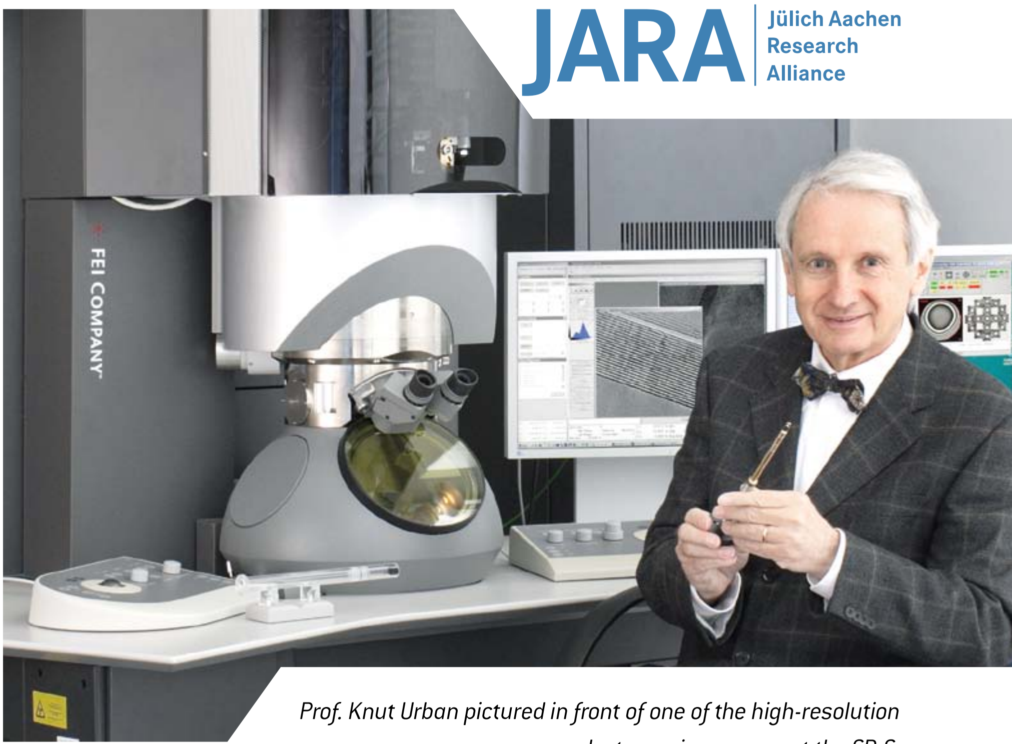
ER-C scientists have also developed software for subsequent image analysis. In contrast to optical microscopy, computer-assisted image analysis is usually required in aberration-corrected electron microscopy. This is because the rules of quantum physics apply when the electron beam hits the atoms of a specimen. For example, the image of an arrangement of atoms depends on the thickness of the specimen and contrast from "atoms" may appear in the image in places where there are no atoms in reality. This problem can only be avoided directly – without computer assistance – by using very specific imaging and specimen conditions.

In order to record images of atomic columns with an electron beam, they must display sufficient contrast. However, the imaging of atomic structures is usually achieved by a contrast mechanism that defies our everyday experience. In this imaging technique, the contrast becomes worse the closer the adjustment of the objective lens is to exact focus. In order to obtain contrast in an image, the objective lens is usually "defocused". However, the result then depends sensitively on the chosen focus value. The TrueImage software developed at the ER-C is able to identify information about the imaging conditions from a series of images recorded with various focus values and, in so doing, can also be used to eliminate residual aberrations.

Vibration-Free Installation

Some five kilometres from the Ernst Ruska-Centre, as the crow flies, the world's biggest excavators are used to mine lignite. At this distance, the movement of the ground caused by these machines is not apparent to us. However, the vibrations would disturb the work of the ER-C's ultrahigh-resolution microscopes if the instruments were not housed in a carefully designed building and separated from their surroundings by a complicated isolation system. The new ER-C building meets all of the requirements for magnetic shielding and indoor climate demanded for operation of the microscopes.





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Prof. Knut Urban pictured in front of one of the high-resolution electron microscopes at the ER-C.

Pioneer of Atomic Electron Microscopy

Interview with JARA Senior Professor Prof. Knut Urban

What made you decide to devote a large part of your scientific career in the past twenty years to atomic electron microscopy?

When I was appointed to Forschungszentrum Jülich and RWTH Aachen University in the late 1980s, solid state research in Germany was experiencing an upswing. The goal was to substantially extend the approaching physical limits of semiconductor technology. To do this, it was necessary to understand the functions of materials and components at the atomic level. Unfortunately, electron microscopy could only make a limited contribution to this research. In fact, despite decades of research and development, we had failed to improve electron optics to the point where we could achieve true atomic resolution. In response, just like many colleagues throughout the world, here in Jülich we attempted to perform microstructural research at the threshold of the atomic world. Our endeavours were quite successful. In particular, we managed to use computer-assisted methods to extend the limits of optics. Considering that computer technology was still not sufficiently well developed, the work was painstaking. In addition, a stagnation in the development of electron optics was having severe economic consequences for the associated industry.

How did this unsatisfactory situation change?

Harald Rose, professor of theoretical physics in Darmstadt, had calculated the concept of a correction lens in the late 1980s. This corrector aimed to overcome the drawbacks of magnetic lenses, and in so doing to result in an aberration-corrected electron lens. I met him and Maximilian Haider, head of the electron microscopy department at the European Molecular Biology Laboratory (EMBL) in Heidelberg, at the 1989 meeting of the German electron microscopy society (Deutsche Gesellschaft für Elektronenmikroskopie) in Salzburg. The two researchers were looking for a partner with an excellent reputation in modern materials research for their project to realize the Rose corrector. This opened the door to the atomic world for me. We managed to convince the Volkswagen Foundation to fund the project. It was subsequently realized by Maximilian Haider and his group in 1991 in Heidelberg. We obtained the first atomic images, at least in principle, with the world's first optically corrected electron microscope in 1997, still in Heidelberg. We submitted a paper on our work to Nature. You can imagine how crushed we were when it was rejected. As is so often the case in the history of science, the really new aspects of the work were not immediately recognized. The following year, the paper was published by Nature and it created a sensation.

So did the dream of materials research on an atomic scale finally come true?

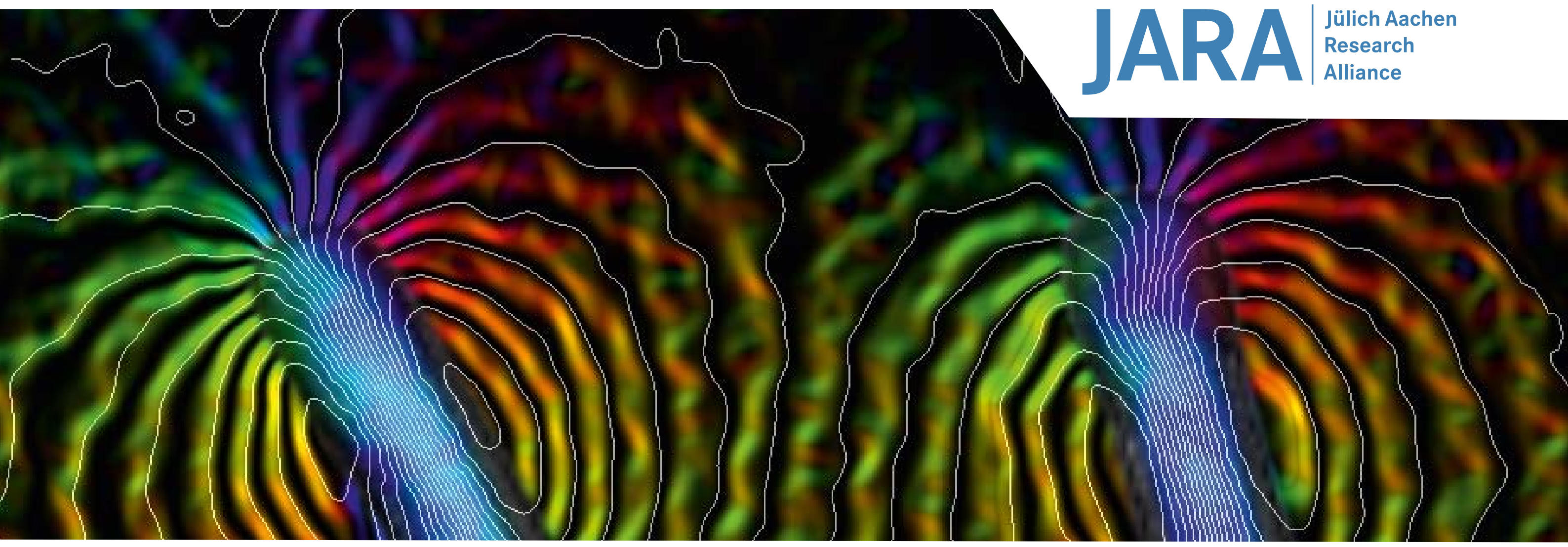
It is true that the door to the atomic world was open. But we couldn't really understand what we saw there. This is because the atomic world is the world of quantum physics. The fact that in Jülich we had already established ourselves as one of the internationally leading institutes in the area of computer-assisted electron optical image computation and image interpretation paid off. To put it in unconventional terms, in atomic electron microscopy what matters is an interpretation of "images" with a brain that understands quantum physics. This brain is a computer that is fed with the laws of quantum physics. Thanks to Jülich's quantum mechanical and optical image interpretation and our state-of-the-art instrument engineering, we can now measure atomic movements in the range of one picometre. This corresponds to about one hundredth of the diameter of a hydrogen atom.

Are such tiny dimensions still relevant for our macroscopic world?

As small as these dimensions are, they are essential for many structure-related properties. Take a ferroelectric memory, for instance, similar to that found in smart cards or some electronic car keys. The digital bits are registered there in the form of displacements of oxygen atoms towards their neighbours on a scale of 10 picometres. The chemical effect of many catalysts for chemical reactions is also associated with such tiny atomic displacements near the catalyst surface.

You retired as the director of ER-C in 2011. Will you continue to share your experience and know-how with the ER-C?

The ER-C and the two operator institutes, PGI-5 in Jülich and the Joint Laboratory for Electron Microscopy (GFE) at RWTH Aachen University, are in an excellent international position with outstanding scientists and unique equipment, along with a highly topical research programme. I have a contractual agreement with the Jülich Aachen Research Alliance (JARA) and I intend to fulfil my obligations in this role. In addition, I was recently named the first JARA Senior Professor. With this in mind, I plan to continue my scientific work here just like any other regular ER-C employee as long as I can. In addition, I have professorships at two universities in China, where I will attempt to recruit well-qualified early-career scientists for the ER-C.



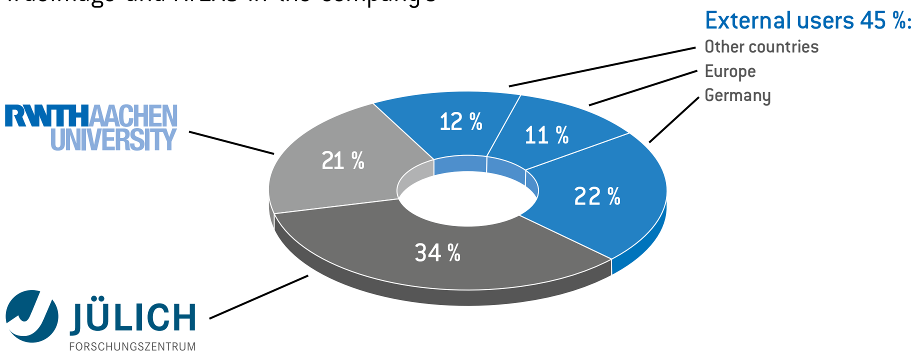
Benefit to Science and Industry

The Ernst Ruska-Centre was founded in 2004 as the first national user centre for ultrahigh-resolution electron microscopy open both to scientists at universities and research institutions and to industry. In addition, the ER-C cooperates with FEI, one of the most innovative companies in the electron microscopy sector.

Half of the usage time of the ultra-high-resolution electron microscopes at the ER-C is available to researchers who are not affiliated with RWTH Aachen University or Forschungszentrum Jülich. This is stipulated in an agreement with the German Research Foundation (DFG) and ensures that the Centre is oriented both to university requirements and also to practical applications. Applications to use the electron microscope must be submitted to the ER-C. A panel of experts nominated by the DFG then reviews the applications on the basis of scientific criteria.

For user operation, the ER-C offers both leading electron optical instruments and facilities for specimen preparation and preliminary examination of electron microscope specimens. Scientists at the ER-C also support users from science and industry with their methodological developments, for instance in the analysis of measured data.

The Centre's researchers also contribute their methodological developments in a cooperation with the electron microscope manufacturer FEI. In this way, they help to integrate software packages such as TrueImage and ATLAS in the company's program routines for high-end instruments. ER-C researchers developed the software themselves and FEI obtained a licence for the programs. TrueImage is already used throughout the world for image analysis. ATLAS serves to diagnose the electron optical state of the instrument (see p. 11). The experts at the ER-C are constantly working to perfect software and methods.



Use of the Titan instruments between 2009 and 2011

Cooperation That Pays Off

Interview with Markus Wild, Managing Director of FEI Deutschland GmbH

The new electron microscope with chromatic aberration correction and two other ultrahigh-resolution instruments at ER-C were purchased from your company. Is the ER-C a run-of-the-mill customer for you?

Not at all. On the one hand, the ER-C has an excellent international scientific reputation. Its outstanding reputation for methodological and technological development is especially important for us. On the other hand, we have already worked together for many years. The scientists at the ER-C always push the limits of what is technically feasible. For an instrument manufacturer like FEI, our cooperation has already paid off, because it allows us to anticipate the next challenges and development steps better.

Are the scientists at the ER-C also responsible for FEI even being in a position to offer ultrahigh-resolution electron microscopes?

Definitely. One sign of this is that the world's first electron microscope with spherical aberration correction was installed in Jülich. Now, these kinds of microscopes are standard. In addition, the scientists at the ER-C have developed software that we commercialize. This software is important for exploiting the possibilities of our microscopes.

What do you expect from your cooperation with the ER-C in the future?

At FEI, we have always considered ourselves to be a technological leader in electron microscopy. With the help of the ER-C, we plan to continue this role. We intend to remain a top supplier, even during times when the competition is jumping on the aberration correction bandwagon.

Markus Wild

How important is it for FEI that the ER-C also allows scientists ouside Forschungszentrum Jülich and RWTH Aachen University to use ultrahigh-resolution electron microscopy?

Of course, we recognize a certain advertising effect. But most of all, we are pleased that this is helping ultrahigh-resolution electron microscopy to take on a more important role in science and in industrial research.

JARA Jülich Aachen Research Alliance

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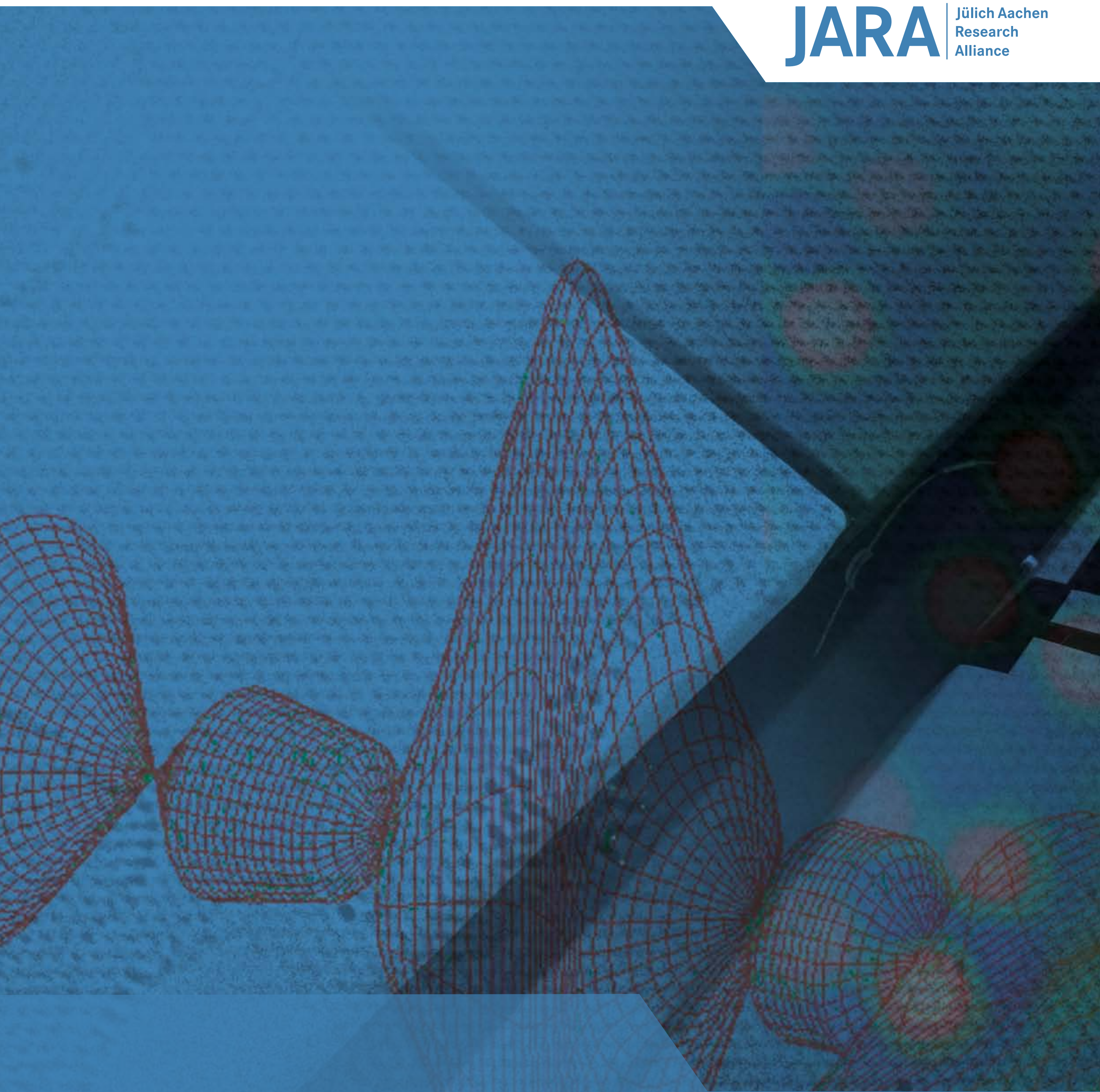

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