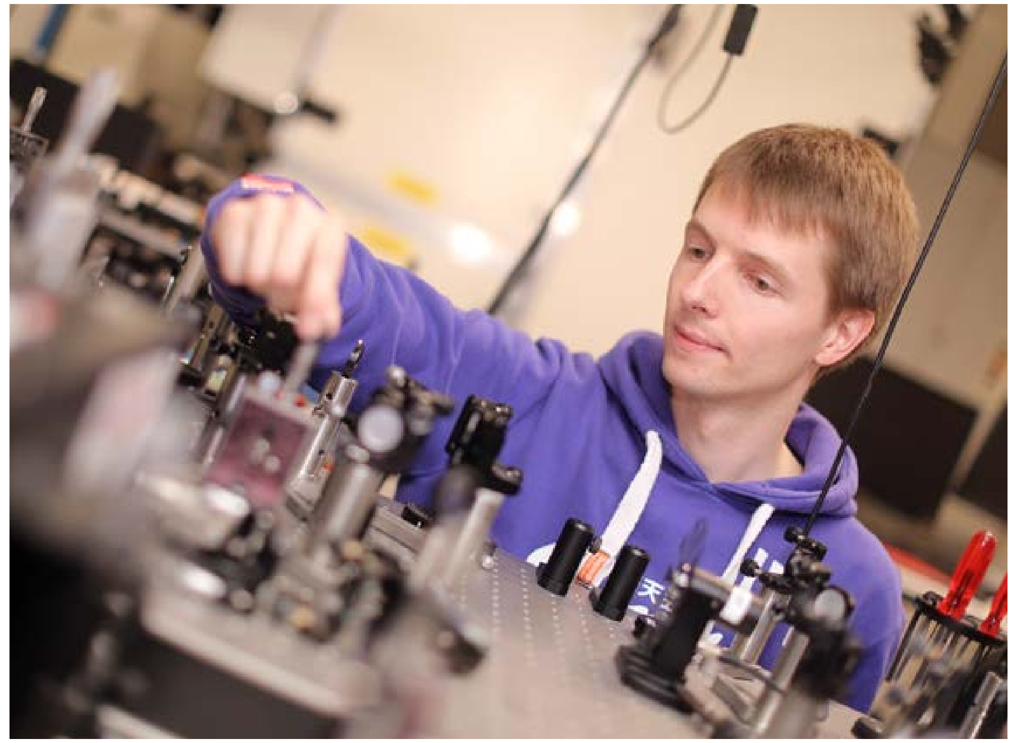
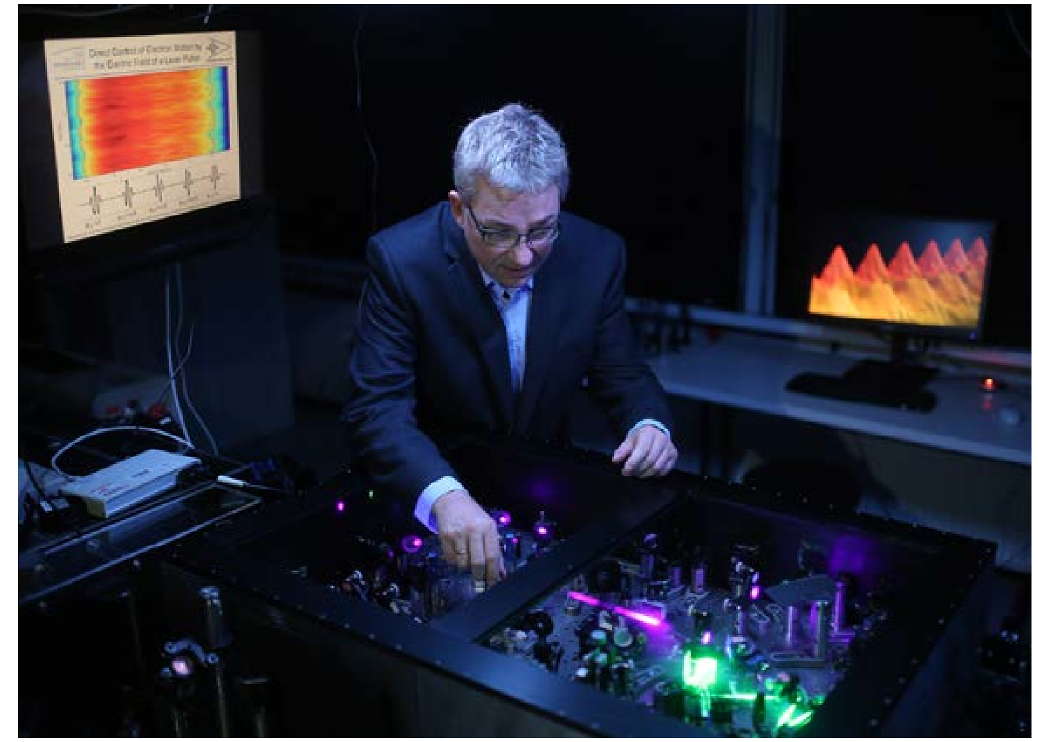
The Tiniest of Worlds

Christoph Lienau studies things that normally remain hidden. He set up the "Ultrafast Nano-Optics" research group at the University, surrounding himself with a team of young researchers. In the international research community Oldenburg is now known as the "city of short pulses"





Competence Centre for Ultrashort Optics: Christoph Lienau and PhD students prepare measurements.

Oldenburg is not only a young and dynamically growing, urban residential city in North-West Germany, home of the "EWE Baskets" or the "City of Science", as it was designated in 2009 by the Stifterverband für die Deutsche Wissenschaft. Oldenburg is, at least for a small community of highly specialised physicists, "the city of short pulses". At the beginning of the year physicist Christoph Lienau was a guest at a scientific conference in Xiamen in South-East China, a city with a population of 3.5 million. Just as he was explaining where he came from a young scientist in the audience interrupted: "Oldenburg, that's the city where they generate these light pulses."

Together with the research group „Ultrafast Nano-Optics" at the Institute for Physics, Lienau has spent the past eight years working hard on earning Oldenburg this reputation within the scientific community. Together they have developed groundbreaking nano-optical technologies that allow for a better understanding and exploitation of the optical properties of nanostructures.

Although the research in ultrafast nano-optics is still at an early stage of its development, "it is one of the most exciting and promising areas of research in physics," Lienau says. And the scientific advances in this field are rapid. In recent years nano research and nanotechnology have become increasingly important for a number of branches of industry. The spectrum of applications ranges from coatings for pans and windows to innovative ultrasound sensors or nanoclusters as computer memory, ultrafast semiconductors and nano-tuning for solar cells. Nanotechnology is even set to play a decisive role in the next generation of computers. Experts predict that the future belongs to optical computers based on nanostructured photonic switches.

And Lienau and his team are shedding light into this tiniest of all worlds. Ultrashort laser pulses can render visible structures and processes that are too minute or too fast to be detected with standard optical microscopes. The laser pulses used by the team are "ultrashort", lasting mere femtoseconds – one femtosecond being equivalent to one billionth of a millionth of a second. Thanks to these pulses it is possible, for example, to gain insight into the function of material structures that are no larger than a ten-thousandth of the width of a human hair.

Lienau concedes that his field of research is the kind of thing that attracts physics freaks, or experimental physicists obsessed with state-of-the-art measurement technology. "We are certainly not doing this work to get rich or to increase the profits of businesses. For the time being our objective is merely the acquisition of scientific knowledge," he explains.

Lienau and his team are conducting basic research to create new knowledge. And the physicist adds with a hint of irony: "It's about getting recognition from people – let's just call them nerds – who have ideas that are as abstract and potentially creative as our own." Ideas that might appear abstruse at first and maybe even absurd because they put traditional knowledge into question. And recognition from such nerds, he says, is a substantial reward.

Competence Centre for Ultrashort Optics

Lienau is certainly getting this recognition. He has published the results of his research in a number of internationally acclaimed scientific journals, such as "Science" and "Nature Photonics". He is now so heavily in demand with his ultrashort laser pulses that he has to turn down invitations to scientific conferences all over the world – due to a lack of time.

The cradle of Lienau's research is the natural sciences campus at Oldenburg University. Here the physicist has set up a very special laboratory. Very few laboratories of this type exist elsewhere in the world. One might call it a competence centre for nanostructure spectroscopy. It is here that the powerful ultrashort pulse laser systems to which the research group owes its success are kept. To the untrained eye the facility looks like a model railway world turned upside down, as if a demented optician had scattered miniature mirrors over a work surface at random. But behind the chaos of light sources, mirrors and prisms is a sophisticated, highly complex system.

Lienau's team has set up all the optical components in the laboratory rooms such that each laser system creates the desired ultrashort pulses for the planned measurements. The undergraduates and postgraduates work with dedication and energy on improving the experimental setups that provide the scientific results for their degree and doctoral theses. The conception and construction of the experiments, the precise alignment of the lasers, mirrors and prisms generally takes several weeks, whereas the actual measurements may take only a few days.

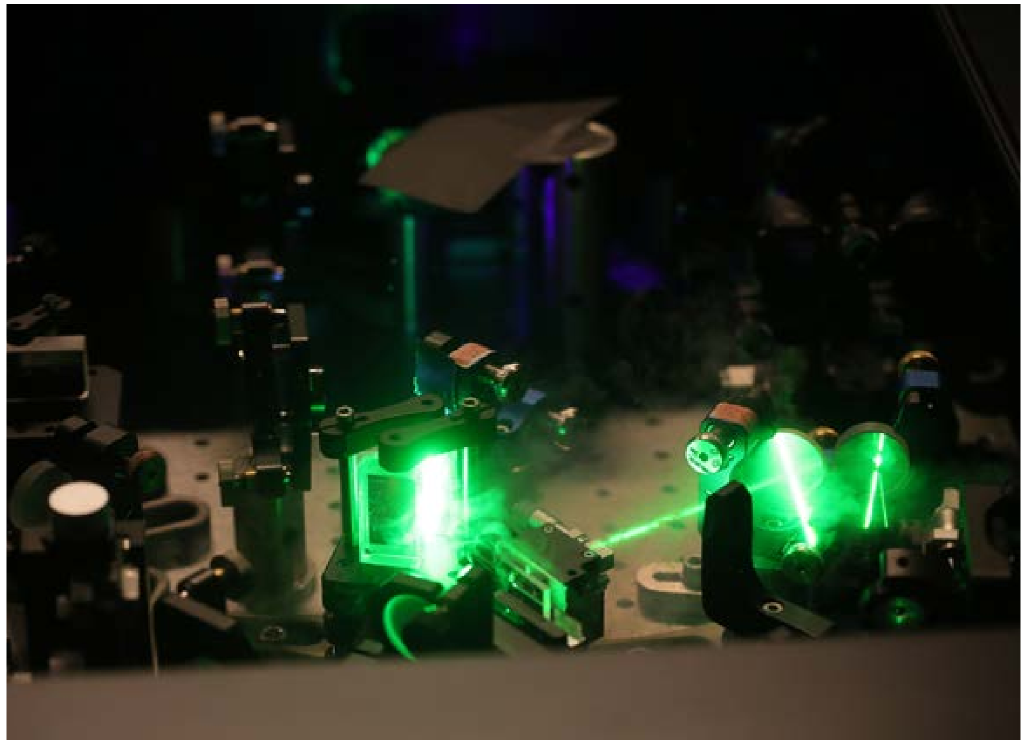
Ultrashort light sources, the laser systems that form the starting point for the experiments, can be purchased from specialist suppliers of scientific equipment, the PhD students explain. But these devices have long since ceased to meet the group's needs. The pulses produced by these lasers are either too long or have the wrong light frequency, which is why they need all the "DIY stuff" – as the doctorate students fondly refer to the arrangements they have designed.

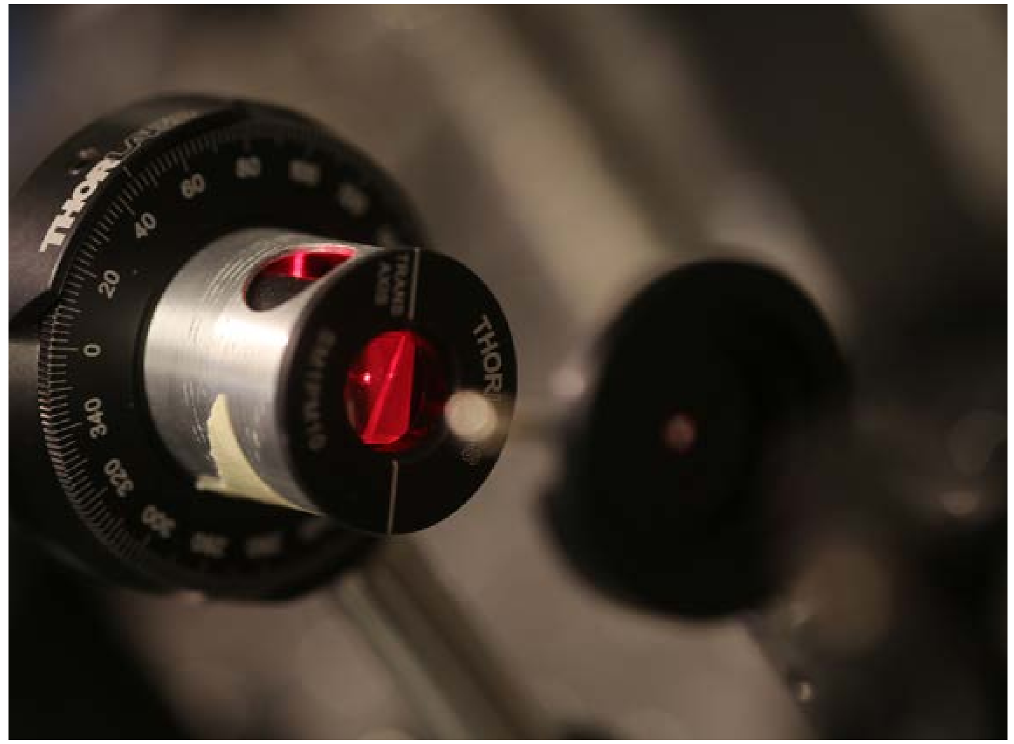
The basis of the sophisticated system of short laser pulses for observing and analysing high-speed dynamic processes are essentially the same technical considerations that exist in photography. If you want to photograph a racing car driving at full speed you need a very short exposure time for the image to get a sharp image.

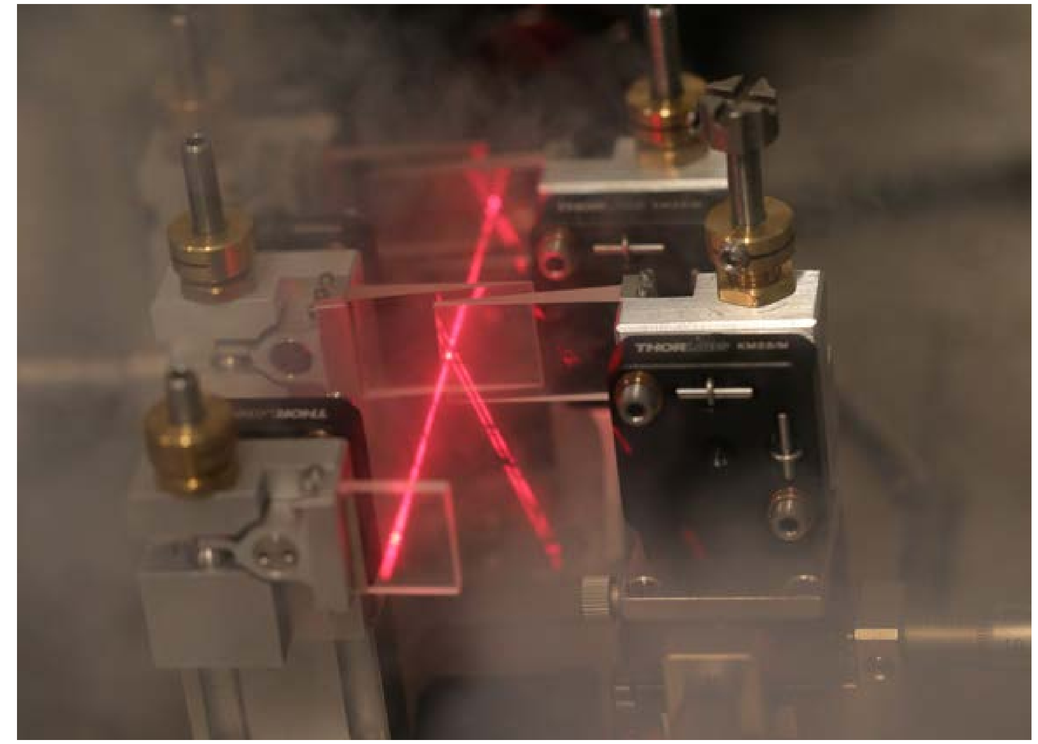
And Lienau's research relies on ultrashort exposure times. When he began his research the temporal resolution of the pulses created was still in the range of 100 femtoseconds. This was sufficient to render visible the motion of atomic nuclei in molecules and thus to track the course of chemical reactions. It was for this work that Ahmed Zewail of the renowned California Institute of Technology, and Lienau's postdoctoral supervisor, was awarded the Nobel Prize in 1999. In the meantime Lienau and his team have succeeded in reducing the pulse duration to significantly less than ten femtoseconds, making it possible to observe the movements of individual electrons. This development will also advance research in the field of renewable energies because it enables direct, time-resolved studies of energy conversion processes in nanostructures, which is highly relevant for renewable energy applications.

Nano-energy Research

It was Prof. Dr. Uwe Schneidewind, president of the University at the time, who gave Lienau the idea of focussing on renewable energies, the physicist recalls with a grin as he looks back on his early days in Oldenburg. "Professor Schneidewind requested ‚research with regional connections to strengthen the University's roots in the region'. And I replied: ‚No, I can't do that at the moment. Our strength lies in basic research. We must use that strength to make a lasting contribution to the University's success.'" Lienau then started to look in detail at the research on renewable energies at Oldenburg University. "When I saw what physicist Jürgen Parisi and his team were







A highly complex system: light sources, mirrors and prisms create the ultrashort laser pulses.

developing in their research on energy and semi-conductors, and what Carsten Agert had set up with his NEXT ENERGY research institute, I realised that here were highly relevant fields of research to which we could contribute. But not just by latching on to what already existed. We needed to use our skills in quantum physics to investigate the microscopic processes of energy conversion in nanostructures, and thus open up a whole new perspective on energy research."

Together with Prof. Dr. Martin Holthaus, then dean of the Faculty of Mathematics and Natural Sciences, the idea was born in 2011 to establish nano-energy research as a new research focus at the University, and to keep the "Ultrafast Nano-Optics" team in Oldenburg. Incorporating more than 80 scientists from the fields of physics, chemistry and biology as well as a "Nano Energy Research" postgraduate programme with 15 PhD students, this area of research has become an integral part of the University.

Basic Research for the Solar Cells of the Future

Commercial batteries, lithium-ion cells, innovative lithium-air batteries, organic solar cells, organic LEDs – they all consist of nanostructures in which energy is converted from one form to another. The most striking example are solar cells; here sun light is converted into electricity. Lienau's team is working on elucidating the microscopic processes that are at play during the light-to-current conversion in solar cells.

"In solar cells, for example, we look at how electricity is generated at the molecular level," the physicist explains. To do this the researchers break the solar cells down into their smallest components – atoms and molecules – and observe their movements on extremely short timescales. Their interest focuses on the interplay between the incident light and the atoms and molecules within the solar cells. In this way the physicists hope to gain an understanding of the microscopic, quantum-mechanical principles of electricity generation.

These processes are so complex that until recently they were beyond the realm of scientific observation. But in his most recent publication in "Science" Magazine Lienau explains how, together with a team of international researchers, he was able to take real-time movies of the conversion of light into electricity in an organic solar cell. In this way the researchers were able to unravel in detail the light-induced electron transfer in such a cell for the first time, and prove that the quantum-mechanical wave character of the electrons plays a key role for this process.

Lienau is thus conducting basic research for future key technologies. He is convinced that his studies and experiments can contribute to the development of more powerful solar cells and batteries in the mid-to-long term. "Some materials are better suited to energy conversion than others. With our nano-optical measuring methods we can study why this is the case right down to the molecular level." And the scientist adds: "In order to increase the efficiency of rechargeable batteries or solar cells we need to understand as best we can the underlying principles of how they work – also to comprehend why nature often resorts to different conversion architectures in biological systems than we physicists and chemists currently use in artificial light conversion systems."

The Spirit of Wechloy

Lienau's research would be inconceivable without a broad national and international network of scientists. He collaborates particularly intensively with Italian research teams from Milan and Modena, internationally renowned experts in ultrafast physics. But at Oldenburg University too, there are many scientists with whom Lienau collaborates on an interdisciplinary basis.

To design and produce new artificial light harvesting complexes, the physicist collaborates closely with Prof. Dr. Jens Christoffers, who teaches organic chemistry. Together with biology professors Karl W. Koch and Henrik Mouritsen he is studying the similarities and differences between biological and artificial energy conversion systems. And within physics, experimental physicist Prof. Dr. Matthias Wollenhaupt, an expert in "customised" ultrashort light pulses, and expert in scanning probe spectroscopy Prof. Dr. Niklas Nilius are both making valuable contributions to nano-energy research.

"We have a rapidly and dynamically developing research culture and a special sense of cohesion at the science campus in Wechloy," Lienau says. Colleagues from other universities have noticed this too. "At meetings and conferences I often hear that Oldenburg has a reputation as a university with close interdisciplinary collaboration among creative researchers. Colleagues envy the short distances we have here, the fact that biologists, physicists and chemists work so well together and are not afraid of making contact, and that their research is mutually beneficial," Lienau explains.

International Young Researchers

Lienau's research is famous far beyond the boundaries of the "City of Short Pulses", a fact also reflected in his research group in which at least 20 German and international junior researchers are working. For example Humboldt fellow Dr. Parinda Vasa, who came to Oldenburg from India as a PhD student to research metallic semiconductor structures using nano-optical methods and to write her postdoctoral thesis on the subject. Even before she had completed her habilitation she was offered professorships at India's most renowned universities. She is currently professor for ultrafast spectroscopy, plamonics and nano-optics at the Department of Physics at the Indian Institute of Technology Bombay. "Word is getting around that we have a thriving research scene here in Oldenburg," Lienau reports, with a touch of pride. "Our PhD students and Postdocs are finding excellent jobs all over the world."

The scientist hopes that the "Nano-Energy Research" postgraduate programme he is running together with the Hochschule Emden/Leer and which is funded by the state of Lower Saxony will generate new important research ideas and will further increase the international visibility of the Oldenburg groups. The programme combines high-profile scientific problems in energy research with basic research in physics and chemistry. Lienau is confident that it offers an excellent opportunity to attract even more talented and eager young scientists to Oldenburg.

And Lienau has his sights set even on the youngest scientists. Last year chemistry and physics teacher Silvia Beckhaus set up a nanotechnology laboratory at the Altes Gymnasium Oldenburg together with the "Ultrafast Nano-Optics" group. Here pupils can look at the nano-cosmos through a scanning force microscope. Explaining his commitment here Lienau says: "I find it extremely important to introduce children and youths to this modern research – to inspire enthusiasm for this unique field of research." So there are plenty of indications that Oldenburg will continue to consolidate its reputation as the "City of Short Pulses" in the years to come.