



The future is bright...

Light-based innovations will have a profound impact on the landscape of 21st Century science and medicine, predict MPQ's Professor Dr Ferenc Krausz and Thorsten Naeser...

**U**ltrashort laser pulses hold enormous potential for investigating microscopic processes, which have far-reaching impacts on natural sciences and future technologies. They open up new perspectives for modern medicine.

Light is the tool of the 21st Century. In medicine today, surgeons use sophisticated laser systems to make precise cuts in deep layers of tissue, oncologists detect cancer cells and ophthalmologists correct eye defects. In chemistry, scientists use light to explore the properties of protein structures at the atomic scale, and in physics, light is the key to research into quantum phenomena in the microcosm.

At Ludwig-Maximilians-Universität (LMU), München, and at the Max Planck Institute of Quantum Optics (MPQ) in Garching, a team of about 100 scientists of the MPQ-LMU Laboratory for Attosecond and High-Field Physics (LAP) have specialised in the generation and application of ultrashort light pulses. Currently 'ultrashort' refers to a pulse duration of less than 100attoseconds. An attosecond

is one billionth part of one billionth part of a second. It is the time that it takes light (which travels at 300,000km per second) to cover the tiny distance corresponding to the diameter of three hydrogen atoms.

Attosecond light flashes are the shortest processes that humans can control today. They are located in the extreme ultraviolet spectrum of the light. By using attosecond light flashes, researchers gain insights into the movement of electrons in atoms, molecules and solid materials. Electrons play a key role in almost all biological and chemical processes, but they are also indispensable in electronics. Attosecond light flashes are the only means to visualise electron behaviour on an atomic scale – that is, in the order of tenths of nanometres. The findings concerning fundamental processes of nature obtained through these experiments can, among other things, be used to better understand the microscopic causes of diseases, to identify effective treatments or to develop new substances. In addition, attosecond metrology will also play a central part in approaching the ultimate limit of speed in modern electronics.

Central to generating these light flashes and measuring time on an attosecond timescale are the forces that the electromagnetic field of visible and near-infrared laser pulses exert on electrons. With the help of the Nobel Prize-winning frequency comb technique, developed by Professor Theodor Hänsch, LAP scientists for the first time succeeded in ‘taming’ these forces by generating laser pulses with a few precisely-controlled light waves. These laser pulses last only a few femtoseconds (one femtosecond is 1,000 attoseconds). For the first time, the electromagnetic force they exert on electrons can be precisely controlled on an attosecond timescale. Thus, it enables the steering of electron motion in atomic systems.

*‘The findings concerning fundamental processes of nature obtained through these experiments can, among other things, be used to better understand the microscopic causes of diseases...’*

If femtosecond pulses are combined with high energy, they can also be put to use in promising new applications in the area of medicine. If, for instance, the energy of light is concentrated in pulses of about 10 femtoseconds’ duration, the power of the latter will be well in excess of one terawatt. Even though the duration of such multi-terawatt femtosecond pulses is extremely short, they will deliver 10,000 times as much power as a modern nuclear power plant. The immense electric and magnetic forces that the light fields exert during this interval of time are capable of steering and controlling charged particles, such as electrons, protons or ions. The forces of light are able to accelerate electrons almost to the speed of light. These high-energy elementary particles can then be used to produce X-rays. Since it was discovered by Wilhelm Conrad Röntgen in 1895, X-radiation has developed into a crucial aid in the field of life sciences and medicine. In spite of its enormous success however, the currently used X-ray diagnostics reaches its limits when it comes to examining soft tissue particles, for example, tumours in intact tissue.

This gap might be closed in the still very young era of laser-driven X-ray generation. For the first time, terawatt laser pulses are now used to create radiation. This technique, which is presently being developed at the MPQ-LMU Laboratory for Attosecond and High-Field Physics, will make it possible to obtain an entirely new quality of X-radiation by means of laser light. This is referred to as ‘brilliant radiation’. It is achieved by bunching X-rays with a well-defined wavelength (to a beam that is mostly focused in one direction). As demonstrated by recent research carried out by scientists who work for the Munich Centre for Advanced Photonics

Cluster of Excellence, brilliant radiation would enable medical doctors to identify even structures in the order of millimetres, such as tumours in the initial stage of development. In such tumours, the probability of metastasis is still very low. A local therapy, again using laser-generated proton or ion beams, will therefore significantly improve the prospects for healing. Besides an early diagnosis, the imaging process by means of brilliant X-rays is expected to substantially reduce the radiation dose for patients.

Already today, brilliant X-radiation is produced in kilometre-size accelerator facilities. These existing facilities are expensive and not appropriate for everyday applications in medicine. Light-generated X-radiation might change that. The physical foundations for the laser-based generation of X-rays in compact devices have been laid. Now it is time to transfer the results of basic research to application-oriented projects. The newly designed Centre for Advanced Laser Applications (CALA) is intended to put this idea into practice. The new research centre is to be built on the Garching campus as part of the Munich Centre for Advanced Photonics Cluster of Excellence, and it is to be operated by scientists of the Munich-based universities LMU and TU Munich.

CALA will accommodate a state-of-the-art short pulse laser. The primary purpose of this system is to advance biomedical imaging techniques with highly brilliant X-rays and to produce proton and carbon beams from compact, laser-driven sources for tumour therapy. The new laser-based systems, developed by LAP team members, are to combine the generation of brilliant X-ray and particle beams on a laboratory scale in the future. This will lead to significantly less costly application options, which will make the treatment method available to a much higher number of patients. CALA will strengthen the already outstanding and globally known location of Munich for laser sciences and optical technologies, creating challenging jobs for highly qualified people.



Professor Dr Ferenc Krausz  
Director  
ferenc.krausz@mpq.mpg.de



Thorsten Naeser  
Personal Assistant to Professor Krausz  
Max-Planck-Institut für Quantenoptik  
Tel: +49 89 32905 124  
thorsten.naeser@mpq.mpg.de  
www.attoworld.de

