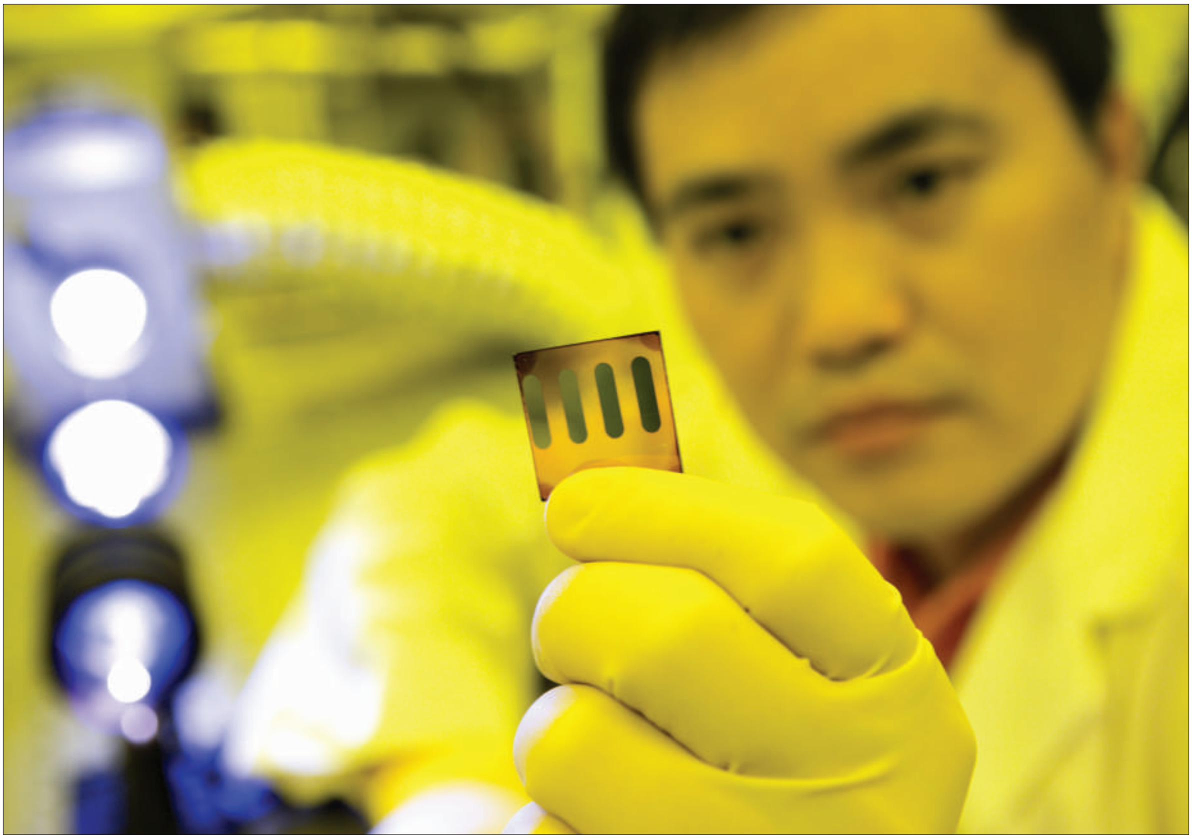

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Holography With Electrons

The principle of holography was discovered in 1947 by the Hungarian scientist Dennis Gábor, in connection with attempts to improve the resolution of electron microscopes. The experimental realization of the concept of holography had to wait, however, until the mid-60s. Holograms were then made using newly-discovered laser light sources, rather than with electrons. Physicists from the Max Born Institute in Berlin have now returned to the use of electrons in holography. A special element in their approach is that the electrons that image the object are made from the object itself using a strong laser.

A report is published in this week´s issue of Science.

Holography, as it is encountered in everyday life, uses coherent light, that is, a source of light where all the emitted light waves march in step. This light wave is divided into two parts, a reference wave and an object wave. The reference wave directly falls onto a two-dimensional detector, for example a photographic plate. The object wave interacts with and scatters off the object, and is then also detected. The superposition of both waves on the detector creates interference patterns, in which the shape of the object is encoded.

What Gábor couldn't do, to construct a source of coherent electrons, is commonplace in experiments with intense laser fields. With intense, ultra-short laser fields, coherent electrons can readily be extracted from atoms and molecules. These electrons are the basis for the new holography experiment, which was carried using Xe atoms. Marc Vrakking describes what happens: "In our experiment, the strong laser field rips electrons from the Xe atoms and accelerates them, before turning them around. It is then as if one takes a catapult and shoots an electron at the ion that was left behind. The laser creates the perfect electron source for a holographic experiment."

Some of the electrons re-combine with the ion, and produce extreme ultra-violet (XUV) light, thereby producing the attosecond pulses that are the basis for the new attosecond science program that is under development at MBI. Most electrons pass the ion and form the reference wave in the holographic experiment. Yet other electrons scatter off the ion, and form the object wave. On a two-dimensional detector the scientists could observe holographic interference patterns caused by the interaction of the object wave with the Coulomb potential of the ion.

In order to successfully carry out the experiments, certain conditions had to be met. In order to create the conditions for holography, the electron source had to be put as far away as possible from the ion, ensuring that the reference wave was only minimally influenced by the ion. The experiments were therefore carried out in the Netherlands, making use of the mid-infrared free electron laser FELICE, in a collaboration that encompassed -- among others -- the FOM Institutes AMOLF and Rijnhuizen. At FELICE, the Xe atoms where ionized using laser light with a 7 mm wavelength, creating ideal conditions for the observation of a hologram.

The ionization process produces the electrons over a finite time interval of a few femtoseconds. Theoretical calculations under the guidance of MBI Junior Group Leader Olga Smirnova show, that the time dependence of the ionization process is encoded in the holograms, as well as possible changes in the ion between the time that the ionization occurs and the time that the object wave interacts with the ion. This suggests a big future promise for the new technique. As Vrakking states: "So far, we have demonstrated that holograms can be produced in experiments with intense lasers. In the future we have to learn, how to extract all the information that is contained in the holograms. This may lead to novel methods to study attosecond time-scale electron dynamics, as well as novel methods to study time-dependent structural changes in molecules."

Y. Huismans, A. Rouzée, A. Gijsbertsen, J. H. Jungmann, A. S. Smolkowska, P. S. W. M. Logman, F. Lépine, C. Cauchy, S. Zamith, T. Marchenko, J. M. Bakker, G. Berden, B. Redlich, A. F. G. Van Der Meer, H. G. Muller, W. Vermin, K. J. Schafer, M. Spanner, M. Yu. Ivanov, O. Smirnova, D. Bauer, S. V. Popruzhenko, and M. J. J. Vrakking. Time-Resolved Holography with Photoelectrons. Science, 16 December 2010 DOI: 10.1126/science.1198450