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Press release

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First step towards nuclear atomic clock

Researchers from Garching have developed a laser source in the extreme ultraviolet spectral region – multiple applications await holds promise for numerous applications

Mode-locked lasers, emitting a train of ultrashort light pulses, have previously enabled the direct counting of the oscillations of visible light. This opened new perspectives, for instance for highly precise optical atomic clocks. The frequency spectrum (the color composition) of such a laser consists of a regularly spaced series of narrow lines, resembling the teeth of a comb. Now researchers from the groups of Theodor W. Hänsch and Ferenc Krausz at the Max-Planck-Institute of Quantum Optics in Garching have developed a light source that provides such a "frequency comb" in the extreme ultraviolet (XUV) spectral region (Nature 436, 234-237, July 14, 2005). The distance between the lines of this comb is sufficiently large so that each line can be used in an isolated manner for precision measurements in this hitherto unexplored spectral region (a similar achievement was published by the group of Jun Ye at JILA at Boulder, USA: Physical Review Letters 94 Nr.193201). The new light source emits a close to perfect laser beam and as such opens up the possibility for machining on the scale of a billionth meter (nanometer).

Optical frequency comb technology, as developed in the labs in Garching and elsewhere, has revolutionized optical frequency metrology. It has enabled for the first time to construct reliable atomic clocks that use an atomic transition with optical frequency for timing. These clocks are projected to reach a precision a thousand times higher than the best existing cesium atomic clock. In general a faster clock timing oscillator allows a finer the subdivision of time and, as a consequence, the clock will be more accurate. While the clock's oscillator of grandfather's pendulum clock oscillates roughly once per second, the quartz in a wrist watch vibrates about 35,000 times, and those of modern cesium atomic clocks ten billion times per second. The latest optical atomic clocks oscillate even a hundred thousand times faster. A further increase of the clock oscillator frequency by use of a vibrating atomic nucleus could become possible by the XUV frequency comb. With the newly developed laser source the researchers in Garching have come a major step closer to this goal.

"Nonlinear conversion" of electromagnetic waves denominates the generation of light in an appropriate medium with a frequency that is an integer multiple of the frequency of the original light. This enables the generation of XUV or even soft x-ray radiation from visible or infrared light. In order to make this conversion efficient, very high power is necessary which so far is achieved by concentrating the average power from a laser into a few (usually several thousand per second) ultra-short light pulses. In this manner, the power in such a light pulse can be increased to some hundred billion watts, without having to increase the radiated average power of several watts. But even with such high power per light pulse, conversion to the XUV is inefficient. At most, 1/100,000 of the total power is converted and the major part of the incident power is lost.

The Garching research group used a trick to circumvent these obstacles: pulses from a laser with a high repetition rate are stored between two (or more) mirrors in such a way, that every newly incident pulse adds to the pulse circulating in the mirror arrangement and thus augments its power up to many hundred times. Placing the nonlinear medium for frequency conversion within this arrangement, makes the conversion into the XUV region possible at very high repetition rates (more than hundred million pulses per second). Furthermore, light that is not converted at one pass through the medium and lost after that, is kept in storage between the mirrors and can contribute at later passes through the medium. Such a source is not only of interest for basic research and high-precision spectroscopy. Its simplicity and compactness, along with its high repetition rate may make applications in the semiconductor industry and high-density holographic data storage possible.

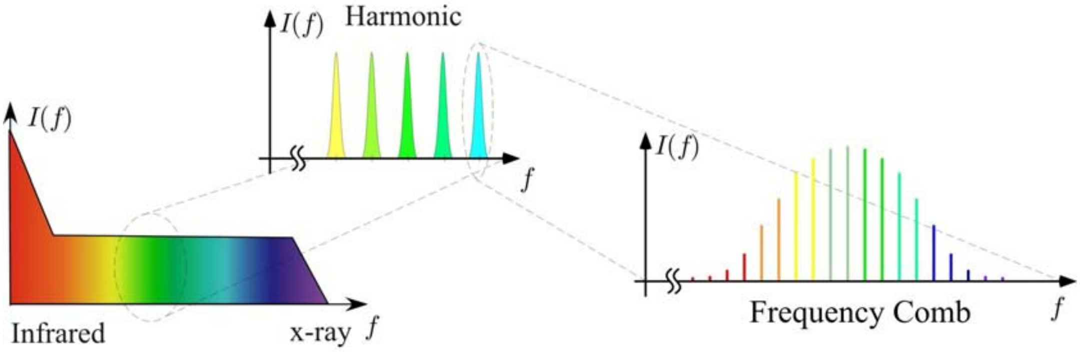

Fig.1
The figure shows the spectrum of the generated harmonic XUV radiation (*f*: frequency). Roughly speaking, every color is generated, starting from the near-infrared laser radiation up to the so-called cut-off frequency (usually resides in the XUV or soft x-ray region). A closer look reveals that this broad spectrum contains narrow lines at frequencies that are odd integer multiples of the near-infrared laser frequency. An even closer look at such a line, a so-called harmonic, shows that it consists of a frequency comb, multiple lines with perfect equidistant spacing. These lines can serve as a "ruler" in frequency space and as such measure with high precision the frequency of light.
Image: Max-Planck-Institut für Quantenoptik

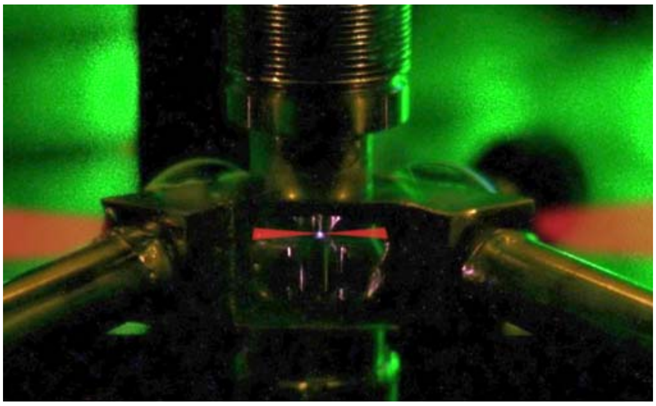

Fig.2
The image shows the vacuum chamber, in which the nonlinear medium is placed (a xenon atom jet), while in operation. The white dot (behind the observation window in the lower half of the image) is caused by xenon atoms that are being ionized by the incident infrared laser light (invisible, therefore symbolized by the red area). The generated XUV radiation can be detected at the vacuum tube in the lower right corner of the image. Dimensions of the chamber are approximately 2 x 1 x 1 centimeter.
Image: Max-Planck-Institut für Quantenoptik

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