World's First UV 'Ruler' Sizes Up Atomic World

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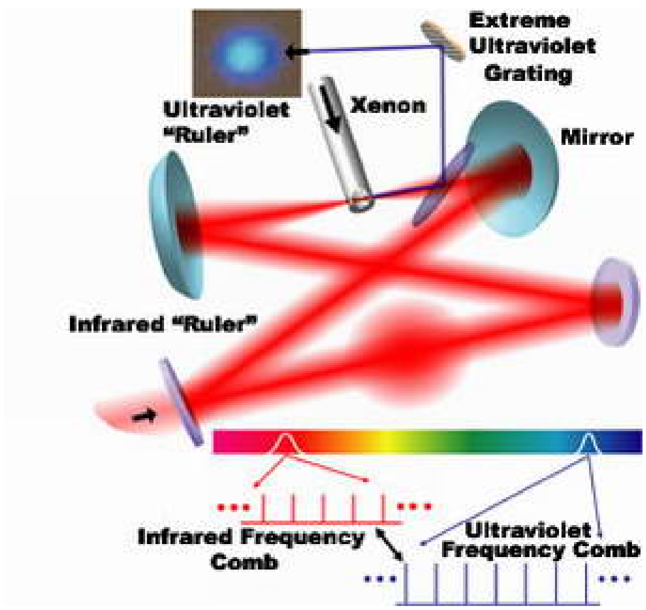

The world's most accurate "ruler" made with extreme ultraviolet light has been built and demonstrated with ultrafast laser pulses by scientists at JILA, a joint institute of the National Institute of Standards and Technology (NIST) and the University of Colorado at Boulder.
The new device, which consistently generates pulses of light lasting just femtoseconds (quadrillionths of a second, or millionths of a billionth of a second) in the ultraviolet region of the electromagnetic spectrum, is described in the May 20 issue of Physical Review Letters.*

Image: The new JILA ultraviolet "ruler" is made by exposing xenon gas atoms to a special type of infrared laser light called a femtosecond frequency "comb." The laser light is bounced back and forth between highly reflective mirrors to increase its intensity. The process causes the highly excited xenon to emit ultraviolet light pulses spaced identically to the original infrared comb. The new comb improves the precision of measurements at the shorter UV wavelengths, just as a faster shutter speed improves the ability of a camera to "see" shorter-lived events. Credit: JILA

The device is expected to become an important tool for ultraprecise measurements in many fields of science including chemistry, physics and astronomy. A ruler made with shorter wavelengths of light makes it possible to "see" more precise differences than ever before in the energy levels of light emissions that identify specific atoms, in the timing of chemical reactions, or, if additional applications are developed, in the dimensions of certain nanometer-scale objects.

The new device also can be compared to a camera with ultrafast shutter speeds and consistent shot-to-shot frame speed and stability, allowing scientists to take real-time “pictures” of finer structures and dynamics. By combining many such pictures at a high speed, scientists can gain a more detailed understanding of many phenomena.

“This ultraviolet light source has a spectacularly high resolution,” says Jun Ye, a NIST Fellow who leads the JILA research group. “On the technological side, the system we used to produce this light is simple and low cost, without active amplifiers.”

The new laser device generates a “frequency comb,” so-called because the frequency spectrum—a graphical representation of the pattern made by many successive laser pulses building on each other—looks like the evenly spaced teeth of a hair comb. (See graphic.) The new comb is a short-wavelength version of the optical frequency combs that in recent years have enabled demonstrations of optical atomic clocks, which are expected to be as much as 100 times more accurate than today's microwave-based atomic clocks. A femtosecond comb, because of its high speed (or repetition rate), has the finest teeth of any optical ruler.

The JILA device uses a process called "high harmonic generation" to transform infrared laser pulses with micrometer-sized wavelengths into higher-energy ultraviolet light with wavelengths on the order of tens of nanometers. The transformation occurs when intense laser fields irradiate highly stable gases such as xenon. The gas atoms are ionized, and the liberated electrons are then driven back to the parent atom by the light field and emit light at frequencies that are multiples of the original laser frequency. The result is a comb in a different region of the electromagnetic spectrum that maintains the same consistent distance between the teeth as the original comb.

In the past, scientists have relied on amplifiers at low repetition rates to reach sufficiently high light intensity for the harmonic process, but the consistency of comb structures was lost. Other designs for short-wavelength light sources have typically been complex and costly. The JILA team overcame these problems by coupling a low-pulse-energy but high-repetition-rate femtosecond laser to a high-quality cavity equipped with a xenon gas jet. The laser light bounces back and forth through the ionized gas between six customized mirrors in a vacuum. This process enhances the light intensity nearly 1,000-fold while maintaining the comb structure through hundreds of round trips.

The mirrors are highly reflective and designed to efficiently focus the light. The JILA team developed the specifications and characterization techniques for the mirrors. The longer the mirrors can keep the light circulating through the ionized gas samples without the pulses spreading out and losing their shape, the shorter the wavelengths that can be generated.

The system is simpler than conventional short-wavelength light sources, using a standard laser as an oscillator without complicated methods of actively amplifying pulses. The continuous “recycling” of the laser light by the mirrors also significantly improves the efficiency of comb production compared with conventional systems.

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*R.J. Jones, K.D. Moll, M.J. Thorpe, and J. Ye. 2005. Phase-coherent frequency combs in the VUV via high-harmonic generation inside a femtosecond enhancement cavity. *Physical Review Letters*. May 20.

Source: NIST