Core solutions reach optimally extreme light pulses

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As scientist probe nature ever more precisely with laser pulses, now aiming for the zeptosecond regime - a trillionth of a billionth of a second and the fastest scale of time measured - optimizing each parameter of those pulses can offer more finely tuned measurements of as-yet unknown dynamic properties. The laser wavelength, duration and energy of each pulse, and rate at which pulses are produced are all key factors in observing dynamics such as the real-time electron motions of single molecules together with the motion of consistituent atoms.

Long wavelength (infrared), high-energy pulses produced hundreds of thousands of times per second are still very difficult to produce. These are necessary conditions, however, for creating x-ray radiation with enough energy to overcome water interactions which currently limit the use of x-ray microscopy of living specimens.

A European-based research collaboration between The Institute of Photonic Sciences (ICFO), Spain, and the Max Planck Institute for the Science of Light (MPL), Germany, now reports the development of such a source, producing 9.6 watt mid-infrared (mid-IR) pulses, at a repetition rate of 160 kilohertz, by using an innovative fiber geometry and parametric amplifier together.

Each pulse consists of a single cycle of the optical wave generated from a gas-filled, hollow-core photonic crystal fiber that does not require external compression, an external signal processing that other systems typically require to produce such clean pulses. The results of this research will be presented during the OSA Laser Congress, 1-5 October 2017 in Nagoya, Japan.

"The significance of our work is the achievement of pulse generation at the ultimate physical limit of one oscillation of the electric field in the mid-IR, and with unprecedented power," said Ugaitz Elu, a doctoral student at ICFO and member of the research team. "The electric field is reproducible, carrier-to-envelope-phase stable, and the application to strong field physics and high harmonic generation should lead to the first isolated waveforms in the hard x-ray and zeptosecond range."

A vital part of producing such short pulses involves their broadening and precise compression. In order to properly overlap the spectrum of frequencies, the team worked to produce the final optical pulse wave.

Chirped mirrors, which consist of multiple stacked coatings to reflect each part of the spectra separately, are often used in fiber laser systems to achieve this compression externally after broadening in the fiber's gas-filled core. In the mid-IR region, however, the fiber would absorb the energy of the pulses before achieving any type of spectral broadening and destroy it. The geometry implemented by Elu and his collaboratators skips this use of chirped mirrors altogether, and achieves both broadening and compression in the fiber.

"Here, we used a specifically designed photonic bandgap fiber whose geometry avoids such absorption," said Elu. "We can achieve broadening and compression in the same fiber without any chirped mirrors."

The energy and time regimes this optical table-top configuration demonstrates allow for a wide array of applications, most notably those stemming from the coherent hard x-rays that they make achievable.

Having a tool to capture dynamics with such precision would open a window to watching, in real-time, the subatomic processes of electrons absorbing and emitting energy during chemical reactions. "Our system is amazingly versatile," Elu said. "For instance, we use it for electron self-diffraction with which we could resolve all the atoms within a molecule while one of its bonds broke."

Provided by Optical Society of America

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