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Single-cycle light

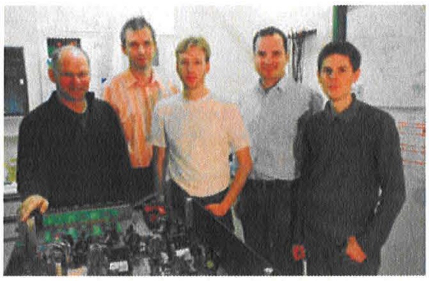
Few-cycle light pulses are important for attosecond science and extremely nonlinear optics. Alfred Leitenstorfer from the University of Konstanz spoke to *Nature Photonics* about how erbium-doped fibre laser technology can generate single-cycle pulses at telecommunications wavelengths.

What have you achieved and how?

We have generated a single-cycle light pulse with a duration of 4.3 femtoseconds in the near-infrared range. To the best of our knowledge, this is the shortest and highest-frequency truly single-cycle pulse demonstrated so far. Until now, the shortest pulse one can find in the visible regime corresponds to about 1.3 optical cycles. Pulse characterization is particularly non-trivial; so far, no established characterization scheme has existed for handling both the ultrahigh bandwidth and relatively low energy of such pulses. Our method of characterization worked in a similar way to the synthesis; we characterized each component separately in amplitude and phase, and then connected both spectra by determining the phase offset with another nonlinear measurement.

What is the physical mechanism behind your work?

The main idea was to generate two ultrashort pulses at different central wavelengths in parallel with the amplifier branches seeded by the same mode-locked erbium-doped fibre oscillator. In this way, each pulse can be optimized separately in terms of high bandwidth and short pulse duration. Because the two branches remained synchronized for 50 attoseconds, which is much less than the time taken for a single cycle of light, we anticipated that it would be possible to coherently recombine the two separate pulses at the end and thus synthesize an even shorter pulse. If two few-cycle optical pulses at different frequencies are superimposed, constructive interference amplifies only a single cycle of light, whereas the rest interfere destructively. The time delay between the pulses has to be set very precisely, and the phase offset must be optimum for constructive interference. This is possible only when the system exhibits extremely low timing jitter and slow drift. We could use a second-order fringe-resolved autocorrelation to monitor how the two pulses approach each other and how they superimpose to form the single cycle. In our work we do not have to use any active stabilization schemes because single-cycle pulse generation is performed at 1.55 μm, where we rely exclusively on bulk optical fibres for frequency conversion. Pulse generation would be much more difficult if we had to work with microstructured or tapered fibres, which are necessary when pumping at shorter wavelengths. Another benefit of the near-infrared frequency range is that we can find materials of prism sequences for compression that exhibit no third-order dispersion at the central frequencies of both pulses. This makes few-cycle pulse compression relatively easy without the need for chirped mirrors or adaptive optics.


UNIVERSITY OF KONSTANZ

Alfred Leitenstorfer, Stefan Eggert, Günther Krauss, Rupert Huber and Alexander Sell (left to right) with their fibre laser system.

What are the implications of your findings?

From a fundamental point of view, we have demonstrated that it is possible to generate a single-cycle pulse of light, and this could be used as a carrier of digital information at telecommunications wavelengths. The pulse duration of 4.3 femtoseconds corresponds to a potential data transmission rate of over 100 terabits per second for a single optical fibre. We are currently using our laser to measure extremely fast plasmon dephasing times in single optical nano-antennas. Such systems would also be very attractive as compact seed sources for attosecond pulse generation and for electro-optic sampling of the field amplitudes of light waves at very high frequencies (beyond 100 THz).

What are the potential applications?

We have already transferred parts of our compact femtosecond fibre laser technology to industrial companies. TOPTICA Photonics AG has set up a line of commercial femtosecond fibre lasers based on our expertise, and in 2009, one of their products was implemented as a light source for a confocal microscope from Carl Zeiss AG. Until now, the main feature of our lasers for real-world applications is their ultrawide tuning range. But short pulses are having an increasingly important role, for example in coherent anti-Stokes Raman microspectroscopy and optical coherence tomography. The ultrahigh bandwidth of our single-cycle pulse would also be interesting for optical phase control and frequency metrology applications. We have also been approached by a company from the space industry for developing an extremely rugged version of our compact set-up, suggesting that it could be used in a satellite as a frequency divider for an optical atomic clock.

What are the remaining challenges and possibilities for future work?

By further decreasing the pulse duration of the solitonic branch, we could reduce the noise of the single cycle. Interestingly, the central peak of the pulse can be optimized very little without increasing the bandwidth. If we calculate the pulse duration that would result with from a perfectly flat phase over the entire spectrum, we would expect further shortening of the full-width half-maximum to less than 100 attoseconds. Our next challenge is to amplify the pulses. Our fibre lasers have already been synchronized with high-power Nd:YAG and Ti:Sapphire pumps. We are currently thinking about an all-fibre set-up with an ytterbium-doped fibre component as an energy source for parametric amplification. Again, our two-branch approach will be beneficial here because the amplification bandwidth can be optimized for each arm before recombination. Attosecond pulse generation will then need stabilization of the carrier-envelope offset frequency of the pulse train. We recently discovered a way to passively phase-lock our system without any electronic stabilization — yet another distinct benefit that comes with using these fibre lasers.

INTERVIEW BY RACHEL WON