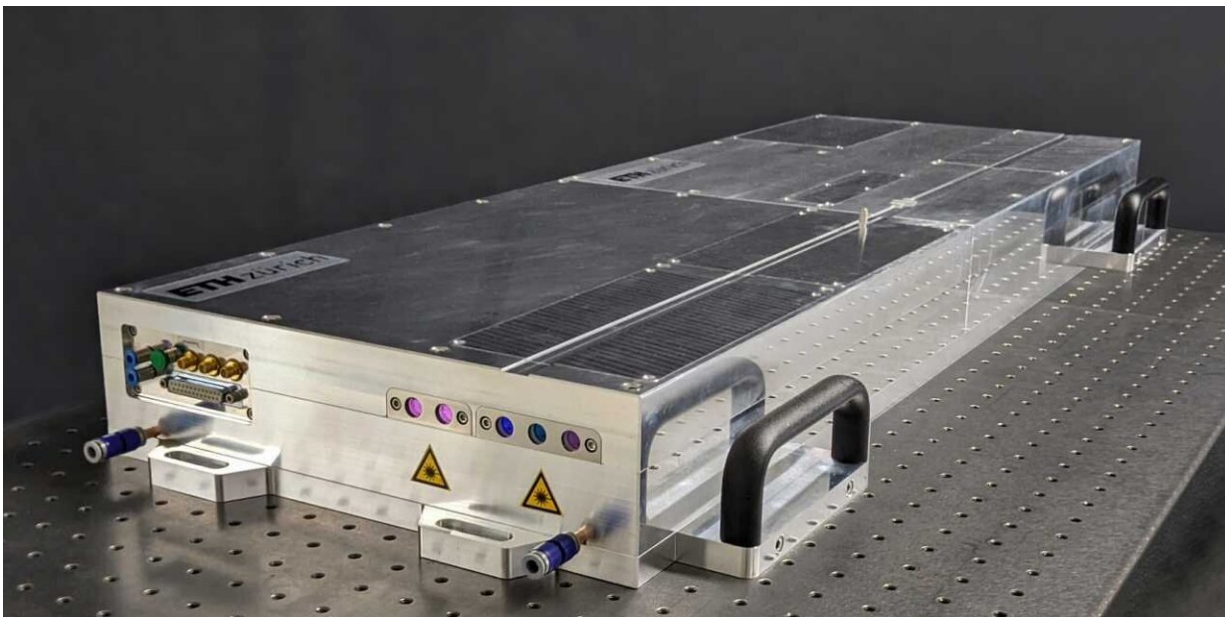


A dual boost for optical delay scanning

November 10 2022



The compact single-cavity dual-comb laser system developed in the Keller group. Credit: ETH Zurich/D-PHYS Benjamin Willenberg

Various applications of pulsed laser sources rely on the ability to produce a series of pulse pairs with a stepwise increasing delay between them. Implementing such optical delay scanning with high precision is demanding, in particular for long delays. Addressing this challenge, ETH physicists have developed a versatile "dual-comb" laser that combines a wide scanning range with high power, low noise, stable operation, and ease of use—thereby offering bright prospects for practical uses.

Ultrafast laser technology has enabled a trove of methods for precision measurements. These include in particular a broad class of pulsed-laser experiments in which a sample is excited and, after a variable amount of time, the response is measured. In such studies, the delay between the two pulses should typically cover the range from femtoseconds to nanoseconds.

In practice, scanning the delay time over a range that broad in a repeatable and precise manner is a significant challenge. A team of researchers in the group of Prof. Ursula Keller at the Institute for Quantum Electronics, with main contributions from Dr. Justinas Pupeikis, Dr. Benjamin Willenberg and Dr. Christopher Phillips, has now taken a major step towards a solution that has the potential to be a game changer for a wide range of practical applications.

Writing in *Optica*, they recently introduced and demonstrated a versatile laser design that offers both outstanding specifications and a low-complexity setup that runs stably over many hours.

The long path to long delays

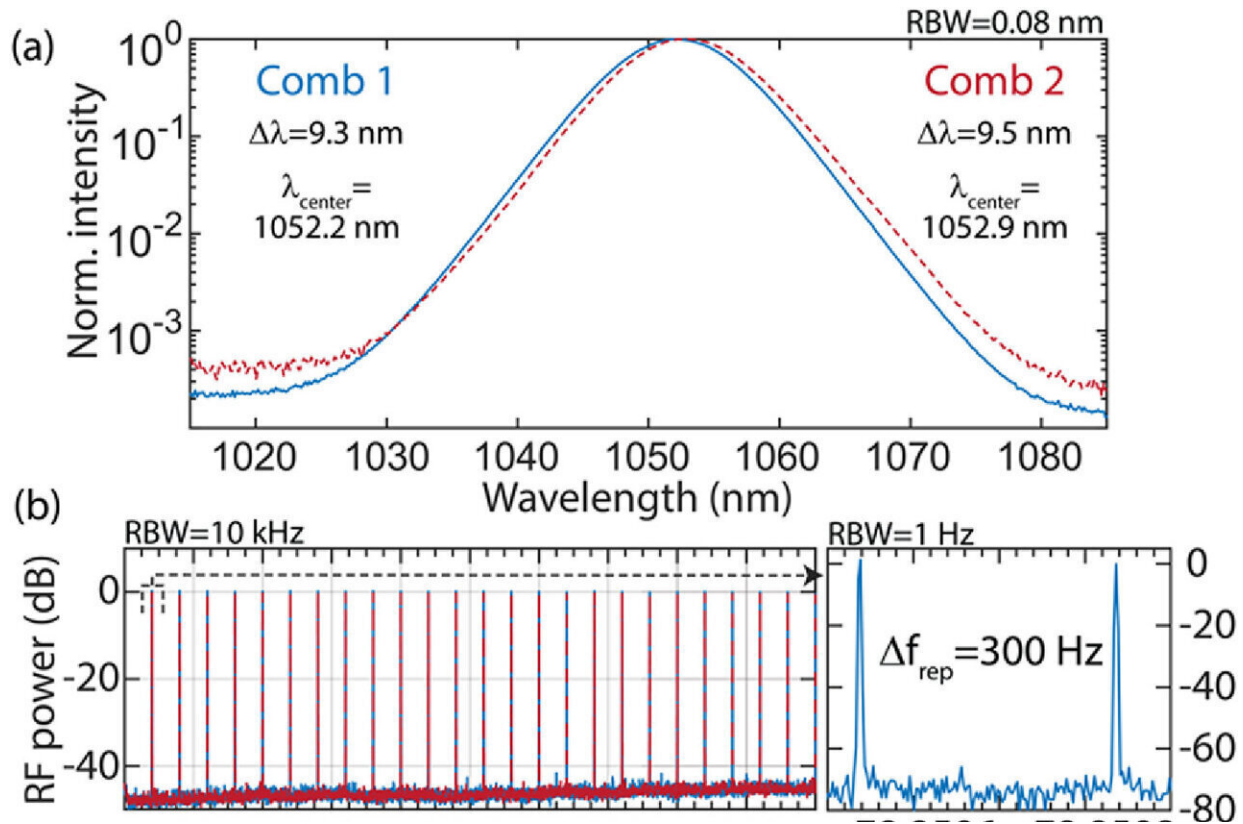
The conceptually simplest solution to scanning optical delays is based on a laser whose output is split into two pulses. While one of them takes a fixed route to the target, the optical path for the second pulse is varied with linearly displacing mirrors. The longer the path between mirrors, the later the laser pulse arrives at the target and the longer is the delay relative to the first pulse.

The problem, however, is that light travels at famously high speed, covering some 0.3 meters per nanosecond (in air). For mechanical delay lines this means that scanning to delays up to several nanoseconds requires large devices with intricate and typically slow mechanical constructions.

An elegant way to avoid complex constructions of that kind is to use a pair of ultrashort pulse lasers that emit trains of pulses, each at slightly different repetition rates. If, say, the first pulses emerging from each of the lasers are perfectly synchronized, then the second pair has a delay between the pulses that corresponds to the difference in repetition times of the two lasers.

The next pair of pulses has twice that delay between them, and so on. In this manner, a perfectly linear and fast scan of optical delays without moving parts is possible—at least in theory. The most refined type of a laser system generating two such pulse trains is known as a dual comb, in reference to the spectral structure of the output consisting of a pair of [optical frequency combs](#).

Whereas the promise of the dual-comb approach has long been clear, progress towards applications was hindered by challenges related to designing a readily deployable laser system that provides two simultaneously operating combs of the required quality and with high relative stability. Now, Pupeikis et al. made a breakthrough towards such a practical laser, and the key is a new way to generate the two frequency combs in one and the same [laser cavity](#).



(a) Laser output spectrum in log scale measured with an optical spectrum analyzer. (b) Normalized power spectral density of the photocurrent generated from a fast photodiode, analyzed with a microwave spectrum analyzer. Inset shows zoom on the first harmonic of the two radio-frequency combs. (c) Repetition rate difference versus the biprism lateral position using a picomotor (Newport). Credit: *Optica* (2022). DOI: 10.1364/OPTICA.457787

Two from one

The task the researchers had at hand was to construct a laser source that consist of two coherent optical pulse trains that are basically identical in all properties except from that all-important difference in repetition rate. A natural route to achieve this is to create the two combs in the same laser cavity.

Various approaches for realizing such laser-cavity multiplexing have been introduced in the past. But these typically require that additional components are placed inside the cavity. This introduces losses and different dispersion characteristics for the two combs, among other issues. The ETH physicists have overcome these issues while still ensuring that the two combs share all of the components inside the cavity.

They achieved this by inserting into the cavity a "biprism," a device with two separate angles on the surface from which light is reflected. The biprism splits the cavity mode into two parts, and the researchers show that by suitable design of the optical cavity the two combs can be spatially separated on the active intracavity components while still taking a very similar path otherwise.

"Active components" refers here to the gain medium, where lasing is induced, and to the so-called SESAM (semiconductor saturable absorber mirror) element, which enables mode-locking and pulse generation. The spatial separation of the modes at these stages means that two combs with distinct spacing can be generated, while most other properties are essentially duplicated. In particular, the two combs have highly correlated timing noise.

That is, while imperfections in the temporal comb structure are unavoidably present, they are almost the same for the two combs, making it possible to deal with such noise.

A gate to practical applications

An outstanding feature of the novel single-cavity architecture now introduced is that it does not require compromises in laser design. Instead, cavity architectures that are optimal for single-comb operation can be readily adapted for dual-comb use. With that, the new design also

represents a major simplification relative to commercial products and opens up a path for the production and deployment of this new class of ultrafast laser sources.

The benchmarks achieved in the first demonstrations are highly encouraging. The researchers scanned an optical delay of 12.5 ns (equivalent to a distance of 3.75 m in air) with 2-fs precision (which is less than a micrometer in physical distance) at rates of up to 500 Hz and with record-high stability for a single-cavity dual-comb [laser](#).

The obtained performance—including the [high power](#) of more than 2.4 W for each comb, the short pulse durations of less than 140 fs, and the demonstrated coupling to an optical parametric oscillator (OPO) for converting the light into a different wavelength regime—underline the practical potential of the approach for a wide spectrum of measurements, from precision optical ranging (the optical measurement of absolute distance) to high-resolution absorption spectroscopy and nonlinear spectroscopy for sampling ultrafast phenomena.

More information: J. Pupeikis et al, Spatially multiplexed single-cavity dual-comb laser, *Optica* (2022). [DOI: 10.1364/OPTICA.457787](https://doi.org/10.1364/OPTICA.457787)

Provided by ETH Zurich

Citation: A dual boost for optical delay scanning (2022, November 10) retrieved 21 June 2024 from <https://phys.org/news/2022-11-dual-boost-optical-delay-scanning.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.
