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Rapid THz-TDS Enabled by Single-Cavity Dual-Comb Gigahertz Laser

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Introduction: The THz spectral region is of high interest for scientific and industrial applications, enabling numerous non-destructive spectroscopy and thickness measurements. While dual comb lasers enable the optical delay sweeps needed for these measurements, most traditional systems are highly complex and have too long delay range. Here we resolve both these issues by demonstrating a single cavity dual-comb modelocked laser with GHz repetition rate based on a new multiplexing technique [1]. This new source supports nanosecond delay scans, sub-75-fs pulses, and multi-10-kilohertz update rates. We perform a proof of principle THz-TDS experiment by driving efficient photoconductive antenna devices [2] directly with the output of the laser oscillator.

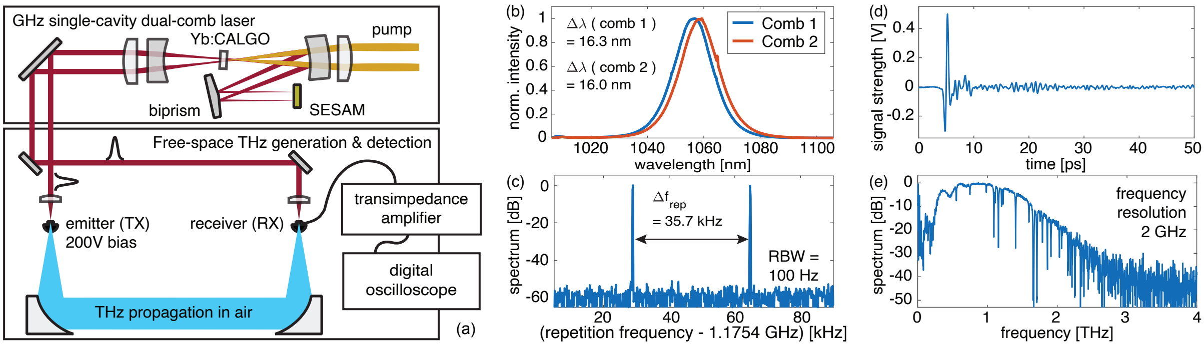

Fig. 1 Experimental setup (a) with single-cavity spatially multiplexed GHz dual-comb oscillator and free-space THz generation and detection. (b) Optical spectrum of the two combs. (c) Microwave spectrum of the two combs around the repetition rate of 1.175 GHz. (d) Averaged THz-signal time trace with a total integration time of 2 seconds. (e) Corresponding THz-spectrum with a frequency resolution of 2 GHz obtained from (d) via a 500-ps apodization window and Fourier transform.

Laser results: The dual-comb oscillator is shown in Fig. 1(a). Spatial multiplexing of the cavity is achieved with a biprism, yielding separate spots on the active elements (gain and SESAM). Additionally, the separation of the beams on the biprism allows continuous tuning of the repetition rate difference Δf_{rep} in a range larger than [-100, 100] kHz. The laser is pumped by a 980-nm diode delivering up to 900 mW of power from a single-mode fiber. The pump power is split equally and focused onto two spots in the Yb:CALGO gain crystal. Both combs show robust self-starting SESAM modelocking over a wide power range (from 60 mW to 100 mW average power per comb). They have a similar optical spectrum (Fig. 1 (b)) with a FWHM bandwidth >16 nm at a center wavelength of 1056 nm (comb 1) and 1058 nm (comb 2) and pulse duration below 75 fs. The fully shared cavity elements lead to common noise cancelation, and the high repetition rate enables a large Δf_{rep} without aliasing of the heterodyne beating between the two combs. Therefore, by using $|\Delta f_{rep}| > 20$ kHz, the two combs exhibit sufficient coherence in free-running operation to directly resolve the radio frequency comb lines and perform coherent dual-comb spectroscopy.

THz experiments: For the terahertz time domain measurements, we send the two combs onto free space THz antennas based on Fe-doped InGaAs [2]. After optical isolation and power control, up to 70 mW can reach each of the THz antenna. For the measurements we use 20 mW on the receiver and 70 mW on the electrically biased emitter. The THz radiation is collected and refocused with a pair of 2-inch parabolic mirrors yielding a path length in air of 265 mm. The receiver electro-optically samples the THz waveform via the delay sweep between the two combs. The generated current is amplified with a low-noise transimpedance amplifier and digitized on an oscilloscope. The THz frequencies are mapped to the RF domain via the dual-comb scaling factor $\Delta f_{rep}/f_{rep}$, where $\Delta f_{rep} = 35.7$ kHz. Using a trigger signal to define the time axis, the data from 71k periods (2 s integration time) is averaged in post processing to yield Fig. 1 (d). The distinct and sharp water absorption lines are visible in the spectrum, obtained by FFT from the time trace. The 500 ps apodization window restricts the spectral frequency resolution to 2 GHz. We achieve 40 dB dynamic range that allows to resolve features up to around 3 THz.

Conclusion: We have shown a single-cavity dual-comb gigahertz laser in free running operation with sub-75-fs pulse duration. The laser allows for direct observation of comb lines without processing on short time scale and with high Δf_{rep} avoiding any acoustic noise sources. We have applied the laser for a THz-TDS demonstration. Ultrafast ns scans, GHz resolution in THz domain, 40dB dynamic range with 2 s average.

References:

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