Single-Cavity Dual-Comb Lasers: Revolutionizing Spectroscopy and Ultrafast Measurements

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The optical frequency comb (OFC) revolution began in the late 1999, marked by three pivotal publications [1-3]. Since then, the field has been a major focus of research, continuously evolving with new innovations. An key advancement in OFC technology are dual-comb lasers, which employs a pair of combs distinguished by a small yet precise difference in their spacing. This allows for rapid pump-probe and spectroscopy measurements without any mechanical delay lines.

We have invented new shared-cavity methods to generate two optical combs with slightly different, adjustable pulse repetition rates. By generating both combs within the same cavity, the system is simplified, and the combs exhibit highly correlated noise properties. These single-cavity dual-comb lasers achieve low noise levels, making them suitable for practical dual-comb measurements. We pioneered two techniques based on polarization [4] and spatial [5] multiplexing. In 2017, the polarization multiplexing approach enabled dual-comb spectroscopy from a single free-running passively mode-locked laser cavity, a key milestone [6].

Since then, we have demonstrated low-noise performance using diode-pumped Yb-doped solid-state and vertical-emitting semiconductor lasers. To verify these low-noise properties, we developed a highly sensitive pulse timing jitter characterization tool [4]. We have demonstrated coherent averaging of dual-comb signals, enabling dual-comb spectroscopy applications with excellent signal-to-noise ratios from free-running dual-comb oscillators without additional stabilization [5]. Many application demonstrations have been done with these lasers, such as picosecond ultrasonics [6], lidar [7], time-domain THz spectroscopy [8], equivalent sampling of SESAM response [9], spectroscopy with adjustable delay intervals [10], 3D microscopy [11], OPO and mid-IR spectroscopy [12] and bio-medical applications [13].

This talk will provide an introduction to dual-comb lasers and highlight several specific application demonstrations.

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