Optical frequency combs from modelocked lasers

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The revolution in optical frequency comb generation started in 1999. This lecture will give an introduction of modelocked frequency comb generation, noise characterization and single-cavity dual-comb generation. I will refer to my new textbook "Ultrafast Lasers" (Springer Verlag 2022) which provides a more comprehensive introduction to fundamental principles and applications.

The frequency comb revolution [1-3] brought two research communities together which had rarely interacted previously. The frequency metrology community was interested in narrowband single-frequency lasers, and the ultrafast laser science community in broadband ultrafast lasers. Both fields were relatively mature around the year 2000, with high-performance single-frequency and modelocked lasers, and with a well-established understanding in both the time and frequency domains in both communities.

This lecture gives a basic introduction to optical frequency comb generation from modelocked lasers, and their noise characterization. For frequency metrology applications the exact position of the carrier (i.e., the electric field below the pulse envelope) needs to be stabilized and controlled. This carrier-envelope offset (CEO) was introduced in 1999 and is referred to as the carrier-envelope offset phase or the carrier-envelope phase. Normally, no locking mechanisms exist between envelope and carrier inside a modelocked laser oscillator, and the relative CEO phase experiences random fluctuations. I will give a basic introduction to optical phase and frequency noise, starting from the basic mathematical principles, CEO phase noise measurement and stabilization techniques based on power spectral densities (PSDs), the connection with intensity noise and timing jitter, integrated noise, and novel measurement techniques for dual-comb noise characterization. The connection between the optical laser spectrum and phase noise is discussed in detail, using the useful concept of the β-separation line. The basic principle of active stabilization and the different laser technologies for optical frequency combs are reviewed.

References

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[2] D. J. Jones et al., Science **288**, 635-639 (2000)
[3] A. Apolonski et al., Phys. Rev. Lett. **85**, 740-743 (2000)