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Versatile and robust Yb:fiber lasers for single and dual-comb applications

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Abstract:

Optical frequency combs, which were originally invented as a high-precision measuring instrument for optical frequencies, have recently also become an indispensable part of optical spectroscopy. However, stepping from the laboratory into field applications represents a major challenge. The highly sensitive light sources used for frequency comb spectroscopy usually react dramatically to real environmental influences such as vibrations or temperature fluctuations.

This thesis describes the generation of robust optical frequency combs based on all-polarization maintaining (PM) fiber lasers and how to optimize them for stability and noise performance. We present the development of an all-PM Ytterbium-doped fiber laser mode-locked using a nonlinear amplifying loop mirror (NALM) in reflection, combined with an nonreciprocal phase bias - also called "figure-9" laser. The use of PM fibers offers higher stability and robustness against environmental perturbations; hence this laser type is a promising candidate for field applications. In very recent years, several different implementations of figure-9 lasers have been reported. However, a detailed analysis of the noise performance and how to operate the laser to obtain the lowest free-running noise has been pending. In order to close this gap, we have developed a particularly versatile figure-9 laser version, that allowed us to characterize the noise behavior as a function of different mode-locking regimes. We give a detailed description of how to optimize the laser in terms of intensity noise and timing jitter as well as how to obtain a narrow linewidth of the free-running comb offset frequency. The laser setup presented here offers a free-running comb offset linewidth of 9.75 kHz at 1 s integration time, which is, to the best of our knowledge, the narrowest linewidth reported so far for this laser type.

As a second topic, we present a novel method to generate two frequency combs out of a single laser cavity with the goal to perform so-called dual-comb spectroscopy - a spectroscopy technique that combines broad spectral coverage and fast acquisition times and shows particular promise for applications outside of the laboratory environment. The novel method presented here consists of implementing a flexible mechanical spectral filter inside the laser, enabling the generation of two pulse trains with slightly different colors and repetition rates out of one single fiber laser. This flexible approach holds two key advantages: the possibility to tune the difference in repetition rates as well as the spectral separation of the two pulse trains.

By merging the stability and robustness of the figure-9 laser design with the tunable mechanical spectral filtering method, we realized an all-PM single-cavity dual-color laser whose functionality is demonstrated in a first proof-of-principle dual-comb experiment.