Microjoule mode-locked oscillators: issues of stability and noises

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Oscillators generating femtosecond (fs) pulses with energy of tens of micro-joules at MHz repetition rate allow direct experiments on light-matter interactions at the intensity levels approaching PW per square centimeter. A broad range of applications with such pulses, like precise pump-probe experiments as well as parametric mixing of the pulses from different oscillators and coherent pulse enhancement in an empty cavity suffer from the instability of the pulse period (so-called timing jitter).

In this work, for the first time to our knowledge, we analyze systematically stability and noise of a thin-disk Yb:YAG oscillator operating in both negative- (NDR) and positive-dispersion (PDR) regimes within a broad range of oscillator parameters. The analysis is based on the stochastic generalized nonlinear complex Ginzburg-Landau equation. It is found, that the energy scaling from 6 micro-joules up to 26 micro-joules in the NDR requires a dispersion scaling from -12000 square fs up to -83000 square fs to provide the pulse stability. Simultaneously, the energy scaling from 6 micro-joules up to 90 micro-joules in the PDR requires a moderate dispersion scaling from 2400 square fs up to 10000 square fs. A chirped picosecond pulse in the PDR has a broader spectrum than that of a chirp-free soliton in the NDR, which allows its compression down to a few of hundreds of fs. A unique property of the PDR has been found to be an extremely reduced timing jitter. It is minimum in the vicinity of the stability border, i.e. for a minimum positive dispersion (the timing jitter amounts to a few of fs for a sub-10 micro-joule pulse), and then the jitter increases up to 120 fs for a 90 micro-joule pulse. The minimum timing jitter in the NDR exceeds 200 fs.

The work was supported by the Austrian National Science Fund (FWF project P20293) and MAP.