Key Regimes of Single-Pulse Generation of Fiber Lasers Mode-Locked due to Non-linear Polarization Evolution

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Abstract. Three key regimes of single-pulse generation of all-normal-dispersion lasers mode-locked due to non-linear polarization evolution are considered. The regimes differ from each other in short-term pulse stability, in shape of spectra and auto-correlation functions.

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All-normal-dispersion (ANDi) fiber lasers mode-locked due to non-linear polarization evolution (NPE) are relatively simple and efficient tool for ultra-short pulse generation what makes them an object of intensive study last years. Compared to lasers mode-locked due to saturable absorbers NPE-lasers have simpler and robust design due to absence of a "weak" elements with respect to radiation power. In comparison with soliton lasers NPE-mode-locked systems are capable to generate pulses with higher pulse energies without wave-breaking [1]. One can achieve further pulse energy growth by elongating cavity of ANDi laser. Since pulse repetition rate of passively mode-locked lasers is inverse proportional to cavity length, the pulse energy growth linearly with cavity length at fixed average pump power. Thus for example pulses with energy as high as 3.9 uJ was achieved in 3.8-km-long passively mode-locked master oscillator [2]. Moreover NPE-mode-locked lasers provides exceptionally wide range of generation regimes being an ideal platform for investigations in non-linear dissipative dynamics [3].

A variety of lasing regimes found in last experiments with NPE-mode-locked lasers with different cavity lengths can be divided into two vast groups: multi-pulses regimes with several pulses co-existed in the cavity at the moment [3,4], and single-pulses regimes. This work is aimed to study key features of single-pulse generation regimes of NPE-mode-locked lasers only. In particular a novel regime that adopts properties of both stable and chaotic generation was shown what allows us to distinguish three main regimes of single-pulse generation that differ from each other in short-term pulse stability as well as in shape of spectra and auto-correlation functions (ACF).

The first of these three regimes is characterized by high temporal stability (with numerically simulated parameters fluctuations from pulse to pulse about $10^{-6}\ldots10^{-4}$), bell-shaped ACF and steep edge spectra. A quite different generation regime in respect to short-term pulse stability is a stochastic or noise-like generation [5], which can be realized in the same ANDi NPE mode-locked lasers with some other settings of cavity polarization elements or/and pump power. In the latter regime the laser produces wave-packets with complex irregular temporal structure included a series of sub-pulses. Integral characteristics of such wave-packets (e.g. duration and energy) experience fluctuations from some percents up to dozens of percents from one cavity round-trip to another. At the same time the inner structure of these wave-packets changes dramatically after a round-trip demonstrating noise-like behavior. There are two different time scales appear for such wave-packets: duration of wave-packet and duration of sub-pulses. The presence of two scales can be readily seen in ACF obtained in experiments and numerical simulations. Smooth ACF pedestal as well as smooth bell-shaped spectra of such wave-packets appear as a result of averaging over a large number of successive pulses whereas ACF and spectrum of each single wave-packet are peaky [6].

Most recent experimental and numerical studies showed that between these two types of regimes there is another one which is characterized by steep spectral edges with smooth declines to zero. ACF in this new regime has a typical double structure but central peak height is much less than the height of ACF pedestal. In other words both spectrum and ACF in this lasing regime occupy intermediate place between those of stable and noise-like regimes, see Fig. 1. Such pulses are a hybrid between stable and chaotic pulses that combines complex chaotic dynamics with self-organization at each moment what differs it from soliton explosion regime [3]. Pulse intensity in the intermediate regime contain high-frequency oscillations but in contrast to noise-like regime intensity does not go down to zero within the pulse. Pulse phase also contains fluctuations that lead to fluctuations in chirp what considerably limits compression ratios of such pulses, however the pulses are still compressible in contrast to noise-like generation [6].

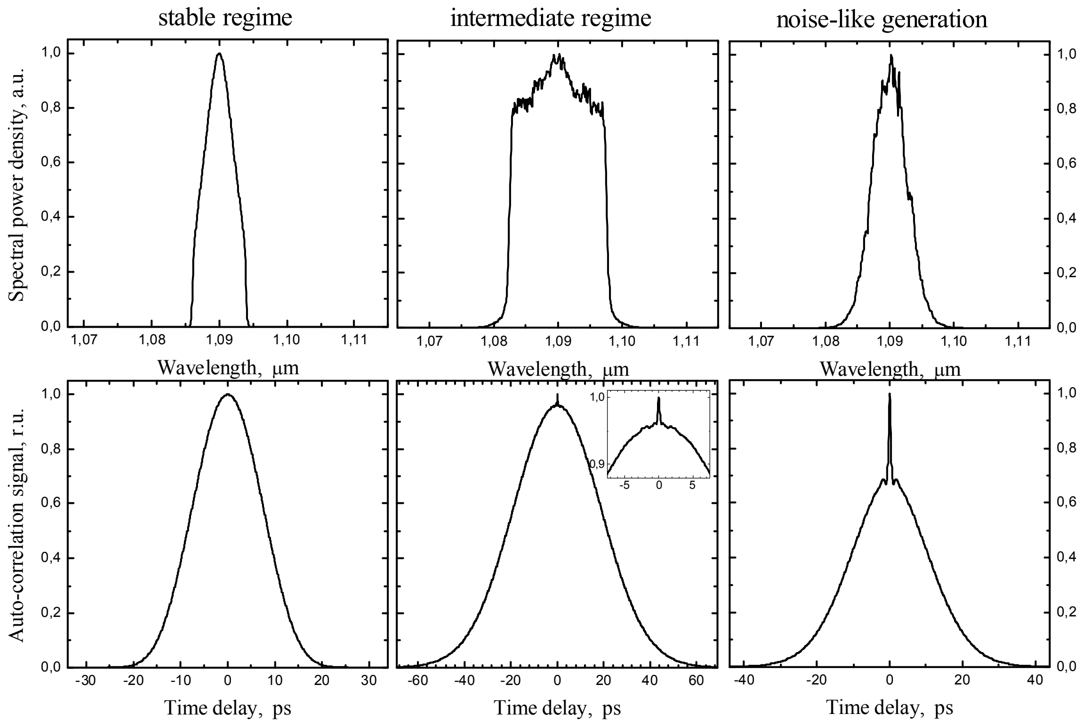

Fig. 1. Spectra and ACF in different generation regimes.

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