Dissipative solitons with controllable duration of sub-pulses

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Dissipative solitons featuring unique spatio-temporal structure of their electromagnetic field are generated in many mode-locked fibre lasers, and especially in fibre lasers with relatively long cavities [1–3]. The attention drawn to such clustered femtosecond or picosecond pulses (sometimes referred to as double-scale or noise-like pulses) stems from their ability to carry record-high energies and average powers directly from fibre-optical master oscillators [4–5] without any subsequent amplification, as well as to exhibit fairly high efficiency of non-linear optical conversion [6–8]. However, controlling parameters of such pulses — shape and duration of their envelope, parameters of sub-pulse filling — is a complicated task because of non-trivial stochastic structure of the intra-pulse electro-magnetic field. Earlier, works [9, 10] demonstrated the possibility of controlling the degree of coherence of such pulsed wave clusters and the effect of their coherence degree on the efficiency of non-linear optical conversion.

This work for the first time presents a study of how the width of an intra-cavity spectral filter affects the structure of double-scale pulses. It is shown that in an actively mode-locked laser, broader spectral filtering leads to shorter duration of sub-structures inside double-scale pulses without at the same time affecting the pulse envelope duration. For the first time demonstrated is control over the average sub-pulse duration (between 1.4 ps and 170 fs) *via* spectral selection.

The influence of spectral filtration was studied in an ultra-long all-fibre laser actively mode-locked by synchronous pumping at the frequency equal to that of the cavity round trip. The studied configuration of the fibre laser is schematically given in Fig. 1.

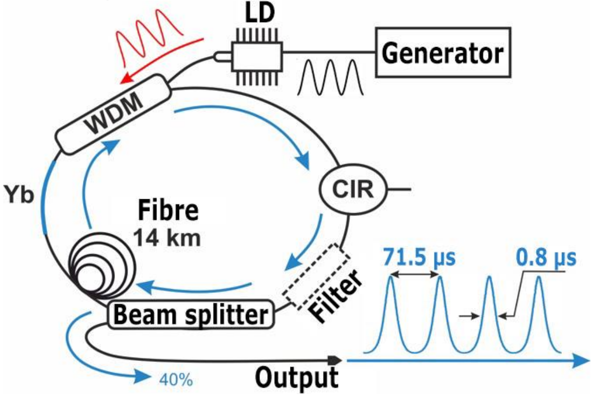

Fig. 1. Fibre laser configuration. LD – laser diode pump, WDM – wavelength division multiplexor for combining the pump and generation waves, Yb – active fibre doped with ytterbium ions.

When the modulation frequency of the pumping laser diode was set to the fundamental cavity round trip frequency the laser generated pulses with the envelope duration of 800 ns.

The studied laser allowed exchanging optical filters. The effect of spectral filtration was estimated from the duration of the central peak of the output auto-correlation function (ACF) corresponding to the average sub-pulse duration. The peak in the centre of the ACF results from beating between various spectral components (superposition of unrelated or weakly related in phase oscillations) present in generation and forming the stochastic sub-pulse filling [11]. Thus, the duration of this central peak is inversely proportional to the width of the generated spectrum and spectral filtration leads to narrower spectrum implying longer sub-pulses.

Depending of the width of the installed filter or its absence, the ACF duration varied from 1.4 ps to 170 fs (Fig. 2). At the same time, the overall duration of the pulse envelope always remained at 800 ns.

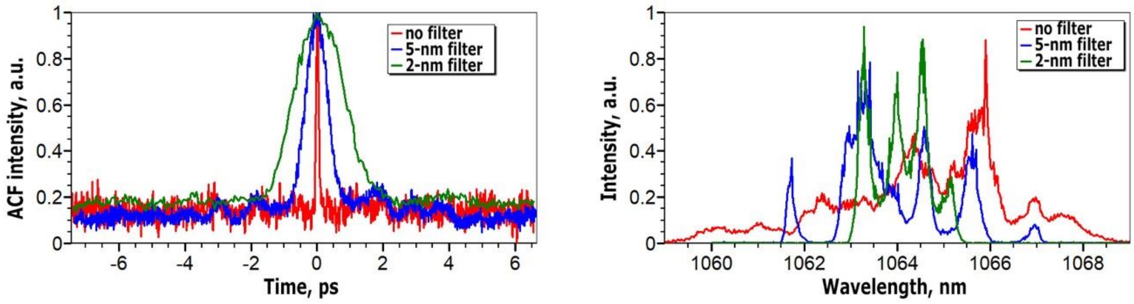

Fig. 2. The central parts of auto-correlation functions and combined optical spectra of double-scale pulses measured at different widths of intra-cavity band-pass filter (central wavelength of the pulse spectrum without filtering is 1030 nm).

The measured results agree well with the model proposed in [11]. As the filter width is broadened by a factor of 2.5 (from 2 nm to 5 nm), that model predicts a reduction of the typical oscillation time (duration of sub-pulses) by the same factor of 2.5, from 1.7 ps down to 680 fs. In our experiment the corresponding figure was 700 fs. The experimental results are in good agreement with the theoretical predictions.

The proposed method creates new possibilities of control over double-scale pulses and their application in various fields of science and technology.

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