Optimization and coherent combining of Raman dissipative solitons in fiber laser

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The regime of dissipative solitons (DS) is a powerful technique for generating high-energy femtosecond pulses in mode-locked lasers based on fiber or other solid-state media [1,2]. Chirped DS pulses are formed inside the laser cavity due to a balanced action of nonlinearity and dispersion (normal), gain and loss. Being intrinsically one-dimensional, stable and hands-free, all-fiber design of femtosecond oscillators is one of the most attractive technologies being intensively developed recently. A key task for the researchers formulated for DS-based all-fiber oscillators is their pulse energy scalability. As shown recently, the DS energy can be increased up to stimulated Raman scattering (SRS) threshold [3,4], achieved for special cavity designs based on a long PM fiber. It was shown that SRS effect converting the excess energy of DS to the noisy Raman pulse at Stokes-shifted wavelengths not necessarily destabilizes the DS [5]. Further development of this idea demonstrated that an intracavity feedback provided by re-injection of the Raman pulse into the laser cavity with proper timing may lead to formation of a coherent Raman dissipative soliton (RDS) [6]. Together, DS and RDS (and second-order RDS) form a two (three) -color complex (see Fig.1.a) of higher total energy.

In this paper we show the results of a detailed investigation of different-order RDSs with the view of their optimization and coherent combining. Optimization of the RDS feedback coefficient in the range of -40-80 dB allowed us to realize experimentally the RDS with minimal value of spectral wings (see Fig.1b) thus providing the highest compression ratio and the highest energy of the chirped DS+RDS complex. The emerging delay between DS and RDS at the laser output originated due to the intracavity group velocity dispersion, can be compensated by an external delay line. After such a step, both solitons (DS and RDS) can be combined coherently (Fig.1c). Due to high mutual coherence of the solitons, the interferometric trace of resulting pulse consists of short (~40 fs) fringes with 75 fs period corresponding to spectral spacing between DS and RDS. The width of the envelope is 450 fs corresponding to a duration of the combined pulse of 300 fs.

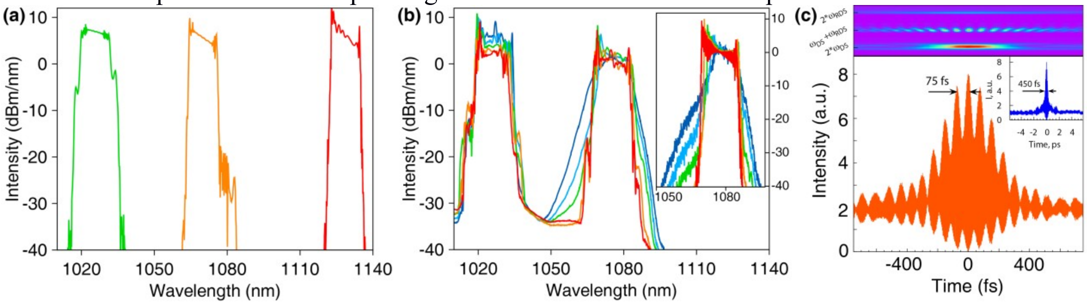

Fig. 1 (a) Simulation of three-color bound solitons; (b) intracavity spectra in experiment and simulation (inset) for the feed-back coefficients -40, -47, -58, -70, -80 dB (from red to blue); (c) FROG and interferometric traces of the combined pulse.

We have found experimentally that an increase of the RDS energy (e.g. by means of intracavity amplification of DS in PM section) results in reaching the second SRS threshold and generating a second-order noisy Raman pulse. This makes principally possible generation of the higher (second- and next) order RDS by adding the second (third etc.) intracavity feedback loop, just like predicted in the simulations (Fig.1a). Besides lasers, other applications can benefit from realization of this approach, including frequency comb spectroscopy, transmission lines, seeding parametric amplifiers and enhancement cavities, multi-photon fluorescence/CARS microscopy etc.

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