Generation of Second-Order Raman Dissipative Solitons in a Fiber Laser

D S Kharenko\(^{1,2}\), A E Bednyakova\(^{1,3}\), E V Podivilov\(^{1,2}\), M P Fedoruk\(^{1,3}\), A A Apolonski\(^{2,4}\), and S A Babin\(^{1,2}\)

\(^{1}\)Novosibirsk State University, 2 Pirogova Str., Novosibirsk, Russia
\(^{2}\)Institute of Automation and Electrometry SB RAS, 1 Ac. Koptug ave., Novosibirsk, Russia
\(^{3}\)Institute of Computational Technologies SB RAS, 6 Ac. Lavrentjev ave., Novosibirsk, Russia
\(^{4}\)Ludwig-Maximilians-Universität München, 85748, Garching, Germany

Contact Email: kharenko@iae.nsk.su

Generation of highly-chirped dissipative solitons (HCDS) is a powerful technique to obtain high-energy femtosecond pulses in mode-locked lasers based on fiber or other solid-state media [1, 2]. Energy scaling can be achieved by increasing mode field diameter [3] or by cavity lengthening [4]. In the second case the energy is limited by the stimulated Raman scattering (SRS) threshold. We have found that this effect can be used for generating a coherent highly-chirped Raman pulses at Stokes wavelengths – Raman dissipative solitons (RDS) [5]. The formation of RDSs is possible with intracavity feedback provided by re-injection of the Raman pulse into the laser cavity with proper timing. As a further development step of this idea, numerical simulation predicted a second-order RDS which can also be generated in a single fiber laser cavity. Together, DS, RDS and second-order RDS form a three-color complex.

In this paper we report on the first experimental demonstration of the second-order RDS and the study of its properties. The regime was achieved by a similar way as the first-order RDS – by adding a second loop of intracavity feedback. It turned out that all the pulses (DS, 1\(^{st}\)- and 2\(^{nd}\)-order RDS) have a chirp parameter of $>100$ and can be externally compressed to 200–300 fs duration. However, we also observed some noise-like pedestal at the output of the compressor (figure 1.b). Its level grows with the soliton order and can be explained by soft (sinusoidal) spectral filters used in the experiment. Detailed numerical simulations showed that a scheme with hard (stepwise) filters provides much better pulse quality (figure 1.c).

We have also found experimentally that an increase of energy of the second-order RDS (e.g. by means of intracavity amplification of a DS by using LD-pumped Yb-doped fiber inserted in a PM section of the cavity) results in reaching the SRS

![Figure 1](image-url)
threshold and starting a third-order noisy Raman pulse (see figure 1.a). This is a necessary prerequisite for generating a third-order RDS by adding the next intracavity feedback loop. Hopefully the next orders of RDSs can be generate in the same way. Besides the development of femtosecond lasers at new wavelengths, 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.

References

[1] P Grelu and N N Akhmediev, Nat. Photonics 6, 84 (2012)